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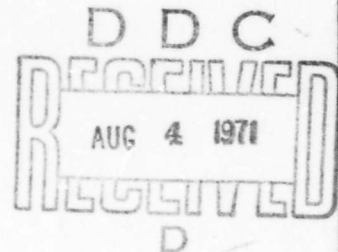
FOREIGN TECHNOLOGY DIVISION



SCIENTIFIC AND TECHNOLOGICAL FORECASTING

by

G. M. Dobrov



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This book is concerned with one of the most urgent problems of scientifically based planning and control of the development of science and technology - contemporary methods of analyzing and forecasting trends in scientific and technological progress. The materials for this book are the most recent developments of Soviet and foreign students of science and also on the research carried out by the scientific collective headed by the author. The book presents the original theoretical conception of scientific and technological forecasting and outlines forecasting methods of interest both for practical planning works in the field of scientific and technological development, and for the projection of complex scientific and technological objects required in advanced scientific information. Similarly, the work is one of the first books in the USSR which systematically outlines and analyzes the contemporary state of scientific and technical forecasting as a complex problem in the study of science. () Since this problem is of interest for wide circles in the scientific and technological community, the book has been written in a form intended for general use.

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TABLE OF CONTENTS

U. S. Board on Geographical Names Transliteration System.....	111
Annotation.....	1v
To The Reader.....	vi
Chapter I. Forecasting - The Science of the Future.....	1
1. A compass on the path to the future.....	1
2. A struggle with the future or a struggle for the future?.....	13
3. Concepts and elements of the theory of scientific and technological forecasts.....	23
Chapter II. Informational and Logical Principles of Forecasting.....	36
1. Prediction potential of scientific and technological information.....	36
2. The treasure-house of ideas.....	47
3. The study of science as the theoretical basis of scientific and technological forecasting.....	56
Chapter III. Forecasting in Conditions of the Contemporary Scientific and Technological Revolution.....	79
1. The law of accelerated development in action.....	79
2. Economic urgency of scientific and technological forecasting.....	90
3. Forecasting and planning in control of scientific and technological progress.....	102
Chapter IV. Contemporary Methods of Scientific and Technological Forecasting.....	117
1. Extrapolation methods.....	117

2. Methods of expert evaluations.....	132
3. Simulation methods.....	153
Chapter V. Urgent Applied Problems of Scientific Forecasting	176
1. The problem of selection.....	176
2. System of forecasts.....	202
3. Algorithm for organization of forecast developments.	206
The Future of the Science of the Future.....	212
References.....	215

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Block	Italic	Transliteration	Block	Italic	Transliteration
А а	А а	A, a	Р р	Р р	R, r
Б б	Б б	B, b	С с	С с	S, s
В в	В в	V, v	Т т	Т т	T, t
Г г	Г г	G, g	У у	У у	U, u
Д д	Д д	D, d	Ф ф	Ф ф	F, f
Е е	Е е	Ye, ye; E, e*	Х х	Х х	Kh, kh
Ж ж	Ж ж	Zh, zh	Ц ц	Ц ц	Ts, ts
З з	З з	Z, z	Ч ч	Ч ч	Ch, ch
И и	И и	I, i	Ш ш	Ш ш	Sh, sh
Й й	Й й	Y, y	Щ щ	Щ щ	Shch, shch
К к	К к	K, k	Ъ ъ	Ъ ъ	"
Л л	Л л	L, l	Ы ы	Ы ы	Y, y
М м	М м	M, m	Ь ь	Ь ь	'
Н н	Н н	N, n	Э э	Э э	E, e
О о	О о	O, o	Ю ю	Ю ю	Yu, yu
П п	П п	P, p	Я я	Я я	Ya, ya

* ye initially, after vowels, and after ъ, б; e elsewhere.
 When written as ѣ in Russian, transliterate as yě or ě.
 The use of diacritical marks is preferred, but such marks
 may be omitted when expediency dictates.

Annotation

This book is concerned with one of the most urgent problems of scientifically based planning and control of the development of science and technology — contemporary methods of analyzing and forecasting trends in scientific and technological progress.

The materials for this book are the most recent developments of Soviet and foreign students of science and also on the research carried out by the scientific collective headed by the author.

The book presents the original theoretical conception of scientific and technological forecasting and outlines forecasting methods of interest both for practical planning works in the field of scientific and technological development, and for the projection of complex scientific and technological objects required in advanced scientific information.

Similarly, the work is one of the first books in the USSR which systematically outlines and analyses the contemporary state of scientific and technical forecasting as a complex problem in the study of science. Since this problem is of interest for wide circles in the scientific and technological community, the book has been written in a form intended for general use.

"...THE ECONOMIST MUST ALWAYS LOOK AHEAD, IN THE
DIRECTION OF THE PROGRESS OF TECHNOLOGY; OTHERWISE
HE IS QUICKLY LEFT BEHIND, SINCE HE WHO WILL NOT
LOOK AHEAD TURNS HIS BACK ON HISTORY: THERE IS
NOT AND CANNOT BE ANY MIDDLE ROAD HERE."

V. I. Lenin,
Complete Collected Works,
Vol. 5, pp. 137-138

TO THE READER

My dear colleague, you and I are living in the most interesting epoch in the history of science. Before the eyes of our generation the last of the "towers of elephant bones," raised so diligently and painstakingly on the high roads of science, have been brought down. The scientist has been transformed from a recluse in his study, divorced from real life, into the original hero of our time -- as a person worthy of the imitation of youth and of maturity as well. Science solidly occupies an ever more determining place in all spheres of life of society; its achievements impinge directly on the majority of the people.

Just what has happened with science in the last twenty years? Indeed, in the scale of its own times the discoveries in science have been again and again no less grandiose.

The fact which stands without historical precedent is the most important consequence of the contemporary scientific and technological revolution -- *the transformation of science in an ever more complete degree and with expansion of the front of the scientific disciplines into a direct productive and social force of society.* The brilliant prediction by Karl Marx that science would receive the "call to be the means for the production of riches*" has come true.

Along with the fantastically growing rates of scientific and technical progress, it has happened that science, always serving the

*"Kommunist," 1958, No. 7, p. 22.

future, has itself brought this future nearer. The changes and consequences which, as a rule, earlier science left for future generations are now occurring within the lifetime and personal responsibility of the direct creators of scientific and technological progress.

"The future has already begun," "tomorrow - the Twenty-First Century" - these are not merely winged phrases, but positive statements of the characterizing feature of the contemporary stage of the history of science and technology. More than half of the scientific and technical knowledge (discoveries, inventions, theories) which will provide a basis for the creators of science and technology at the beginning of the 21st Century will be the heritage of our generation. A large portion of future scientists are already living among us. In our time the most important social and economic conditions for the development of science and for the utilization of the achievements scientific and technological progress are being formulated.

All of this has justified the efforts of scientists to compile some concept of the possible future of science and technology, to develop a scientifically based concept by which we wish to see this future. Research on the forecasting of science and technology - the newest and most important branch of the contemporary science of science (the study of science) - is oriented toward achievement of such goals.

The Resolution of the Central Committee of the Communist Party of the Soviet Union and the Council of Ministers of the USSR published in October of 1968 "On Measures for Increasing the Effectiveness of the Work of Scientific Organizations and Accelerating the Utilization of the Achievements of Science and Technology in the National Economy" placed the business of forecasting science and technology in the number of most important problems of the scientific development of the basis for controlling the development of science and technology. "It is recognized as necessary," it states in the Resolution, "with regard to the most important problems in the development of the national economy, that scientific and technical forecasting for a

prolonged period (10-15 and more years) must be developed in the future. ...Proceeding on the basis of forecasts of science and technology, ministries and departments and Councils of Ministers of the Union Republics will organize the development of designs of establishments and production on a long-term basis, as well as the development of models of the machines and equipment of the future. Here we have in mind guaranteeing the required scientific and technical reserve for transition to qualitatively new technological processes, which will make it possible to increase the productivity of labor by several times as compared with the present level."*

In this book an effort has been made to generalize from single methodological positions the uncoordinated experience in development of forecasting of science and technology. The author desired to examine a number of actual problems in procedure and methodology of scientific and technological forecasting, to discuss certain experience in forecasting work accumulated in the collective of students of science with which he is working.

The work is not intended to play the role of an instruction manual on forecasting of science and technology. The author asks that you regard the generalization which he has made of the experience in forecasting and the positions advanced in the book as addressed to a broad circle of colleagues as an invitation to joint reflection on certain interesting and important problems in the study of science.

In the preparation of the book the author received the irreplaceable assistance of his comrades, coworkers, and scientists working in the Department of Complex Problems in the Realm of Science of the Council on the Study of Productive Forces of the UkrSSR, Ukrainian Academy of Sciences. It is my pleasant duty to express to all of them my deep gratitude.

The Author

*"Pravda," 23 October 1968.

CHAPTER 1

FORECASTING - THE SCIENCE OF THE FUTURE

1. A compass on the path to the future

Karl Marx compared various concerns of science with the ascent on a rocky mountain. This analogy is profoundly valid. And thus far only he reaches the shining summit of the mountain who, without succumbing to fatigue, clambers over its stony slopes. At the same time there are, in this situation, essentially new landmarks: the fantastically growing quantity of individual trails of science, the arming of these sciences with the most powerful technical equipment, increasing the total velocity of movement of the scientific front. In these conditions, as never before, the problem of controlling scientific and technological development has become extremely urgent.

Have you ever had to drive a car over an unknown mountain road? If the speed is great and if the vehicle is heavily loaded, it is impossible to guide it successfully without information about the section of the road ahead, without a compass and map in the hands of he who controls the motion. The instinct developed by highly experienced guiding sciences does make it possible to avoid emergencies, but nonetheless instances when some branches of research have "overshot" turnings on the road which would provide the best route to the goal are very common, as are cases when not enough speed was gained beforehand to begin the next steep ascent beginning in the world science.

In the field of technical creation, no less characteristic is the situation when "tight" spots are detected in a newly constructed shop or factory, requiring reconstruction of an enterprise which has just gone into operation. The reason for this is the failure of a number of vitalized decisions to conform to new techniques and technology appearing after the 10-12 (and sometimes more) years which separate the design stage from the completion of construction of a large contemporary enterprise.

The availability of information on future requirements and the possible results and consequences of controlling actions is a necessary prerequisite for optimum control of any system. For this very reason an element that each and every type of useful human activity is more or less developed foresight of the results of actions which are undertaken. "...The poorest architect," remarked K. Marx, "is distinguished from the very best bee by the fact that before building a cell out of wax, he has already constructed it in his head."*

By its nature the prognostic function is inherent to the scientific systems of knowledge. However, we must immediately note that in the many years of experience of realization of science this one of its functions relates almost exclusively to the objects of scientific study. As regards for seeing the future, science itself and, in particular, the organizational forms of its life activity this type of forecasting has been possible only on the basis of the scientific approach to the study of science itself and of scientific research activity. Scientific and technological forecasting is one of the most important divisions of the contemporary study of science, creating the theoretical principles for control of scientific and technological progress.

The creators of scientific and technical progress from all times and all peoples have left us the richest collection of brilliant guesses and sagacious predictions of the paths of development of science and technology [1].

*K. Marx and F. Engels. Writings, Vol. 23, p. 189.

History contains many examples of brilliant predictions by leading thinkers and innovators of technology from all times and nations. Thus, even in the conditions of the feudal structure, gazing more than six centuries ahead, the English scholar Roger Bacon predicted the appearance and widespread use in the future of such types of technology as self-propelled transport for movement on land, on water, and in the air.

The genius of the great Italian scientist, engineer, and artist Leonardo da Vinci anticipated the idea of oscillatory motion as the basis for the explanation of the nature of light, sound, heat, and magnetic phenomena. He also made sketches of plans for textile and screw-cutting machines, printing devices, submarines, and heavier-than-air craft which appeared to many of his contemporaries as baseless fantasies.

In the middle of the Eighteenth Century the great Lomonosov predicted that in the future "chemistry and electricity will provide enviable service to humanity." The era of technological application of electricity in industry was also foreseen in the 1840's by the English physicist Michael Faraday and the remarkable Russian scientist Boris Semenovitch Yakobi.

Modern space rockets and the jet engines designed for so many purposes personify the development of the ideas of the Newton reaction engine and the brilliant projects of our Russian K. E. Tsiolkovskiy.

The mind of D. I. Mendeleev - the creator of the natural basis of the contemporary structure of chemistry - predicted titanium in the 1860's on the basis of the periodic law which he discovered for the properties of a number of chemical elements unknown at that time. More than fifty chemical elements discovered in the century which has passed since the composition of the Mendeleev table confirmed in every instance its brilliant insight.

One of the pioneers of highly technical education in our country, the great scientist-mechanician Professor V. L. Kirpichev, wrote at the

beginning of the present century in his salute addressed to one of the first publications of the Kiev Poltechnic Institute, of his profound conviction that the Twentieth Century would see people "explore the great forests, cultivate extensive fields and meadows in the desert, complete a net of railways and canals. ...They would cover Russia with numerous factories and plants which would mass-produce a variety of products of the highest quality and cheap besides, so that they could be used by all; that these factories would contain perfected, obedient machines, and that the finest of working conditions would be found there: clean, fresh air, clean working areas, complete absence of danger from the machines, and a short working day" [2].

Another leading figure of Russian science, Academician V. I. Vernadskiy, was one of the first to foresee the consequences of the penetration into the mysteries of the atom which was beginning in his time. He stated in the year 1910: "A source of energy is opening to us before which the power and significance of steam, electricity, and of chemical explosives pale into significance. We, the children of the Nineteenth Century, followed step by step the power of steam and electricity; we know how deeply they have changed and are changing the entire social structure of human society - and more than that - how deeply they have changed the smaller everyday situation of the individual.... And now in the phenomena of radio-activity there is opening before us a source of atomic energy, millions of times exceeding all sources of power which the human imagination has ever drawn."

Subsequently, developing his thoughts on the future use of atomic energy, Vernadskiy added: "This may happen in the near future; it may happen after a century. What is clear is that this will be. Will mankind be able to utilize this force, to direct it toward good, and not towards self-destruction? Scientists must not close their eyes to the possible consequences of their scientific work, the consequences of scientific progress. They must regard themselves as responsible for the consequences of their discoveries. They must connect their work with the better organization of all of humanity" [3].

To fully comprehend the deep wisdom of this prediction by V. I. Vernadskiy, we should remember that he first stated it at the same time in history when one of the creators of the science of radioactivity and the structure of the atom, the great English physicist Rutherford, asserted that discoveries in this region "have no practical value, but only scientific" [4].

Forecasts of scientific and technological progress — this is a very complex and critical matter. It requires not only deep penetration into the essence and laws of the development of science and technology, but also a clear understanding of their interplay with the social forces of human life.

It was not by accident that the ideologists of the bourgeoisie sketched quite gloomy pictures of the future of humanity in connection with the progress of science and technology in their predictions of the Twentieth Century. Analyzing the development of society, the American socialists of the past century, the brothers Brooks and Henry Adams applied the laws of biology, physics and mechanics, formulating the so-called "law of civilization and decline." On the basis of this law they presented the following "periodization" of the development of society: the first, "mechanical phase" — 300 years (1600-1900); the second, "electrical phase," would by their calculations equal $\sqrt{300}$ years, i.e., 17.5 years and, finally, the last "ephemeral phase" would comprise $\sqrt{17.5}$ years, i.e., somewhat more than four years, while in 1921 "the mind will achieve the limits of its capabilities." A general decline and destruction of civilization would set in [5].

In a book published in 1884 in London under the title "The Year 1984" our present time was also characterized as an era of universal "physical and spiritual degradation of humanity."

Such antiscientific pessimistic predictions reflected the deep and organic fears of the historically doomed bourgeois class before the real objective laws of history, and also the fact that scientific and technical progress aggravates the sharp class contradictions existing in bourgeois society as it is.

In this respect the notation made by the well-known French writers, the brothers Goncourt, in their diary in 1870 is characteristic: "They say that Berthelot predicted that thanks to the physical and chemical sciences, in 100 years men will learn what the atom is made of... We do not object to this, but we feel that when this time comes for science, God will come down to Earth with his white beard and, jingling his chain of keys, announce to humanity - as it is announced at five in the morning in the salon - 'Time to close, gentlemen!'" [6].

To the honor of the outstanding French chemist Berthelot it must be noted that he himself did not hold such views of the future. In a remarkable speech given in 1894 he said the following about the 2000th year of humanity: "Fuels will be replaced by chemical and physical processes. Tariffs and wars will be abolished; aerial travel, using the motive power of chemical substances, will have pronounced the death sentence on these obsolete orders.

"The problem of all industry consists in finding a source of power which will be inexhaustible and which can be renewed with the least possible expenditure of labor. The use of solar heat and the heat included within the Earth must be considered. Thanks to terrestrial heat numerous chemical problems will be solved - among others, the greatest problem of chemistry: the manufacture of food by chemical methods... that which up to now has been produced by plants will be accomplished by *industry* and at that *even better*, than nature" [7].

In evaluating these first efforts at scientific and technological forecasting as a whole, we should note that today they can be regarded as nothing more than interesting and instructive factual material. The predicted evaluations had an uncoordinated and disconnected nature. The most justifiable of them were, as a rule, based only on intuition and on the creative imagination of the scientists. The hypotheses advanced for future scientific and technological progress were weakly connected with the social and economic conditions of their realization. Of systematic methods of forecasting, definite

statements could be made only regarding the methods of direct extrapolation and historical analogy. At the same time there was no deficiency of what, bluntly, were not scientific approaches, but approached openly speculative "fortune-telling."

Karl Marx and Friedrich Engels gave a truly scientific explanation of the deep contradictions and moving forces of the development of science and technology for the first time in human history. Marxism not only revealed the original causes of this phenomenon, but it showed a method for constructing a society in which the development of science and technology would be harmoniously combined with the interests of all mankind.

This provided a firm scientific foundation for social and economic forecasting, and also for the unique methodological principles of scientific and technological forecasting, so closely connected with them. It is no accident that all of the predictions of the future of science and technology found in the classics of Marxism have been completely validated in our era.

In their works, Karl Marx and Friedrich Engels predicted the great future of a number of branches of technology born in their time — such, as the first automatic machine systems, the practical use of new chemical discoveries, and the specific features of development of electric power engineering. Concerning the significance the experiments by M. Despres in the transmission of electric power over a distance, Engels stated in 1883:

"...This discovery finally frees industry from almost all limitations imposed by local conditions, making it possible to use even the most distant hydroelectric energy, and while initially it will be useful only for cities, in the end it will become the most powerful lever for eliminating the contrast between city and village. It is completely clear, however, that thanks to this the productive forces will grow so much that their control will be less and less under the power of the bourgeoisie".

*K. Marx and F. Engels. Writings, Vol. 35, p. 374.

The outstanding scientist and propagandist of Marxism, August Bebel, wrote on the threshold of the Twentieth Century in his brilliant work "The Future Society": "Electricity will achieve its greatest use and broadest application only with a socialist system of society" [7].

A. Bebel predicted the broad use in power networks of waterfalls, ocean tides, wind power, and, in particular, solar energy. He dreamed of the future of aviation, serving "to increase the productive forces of society," of the wireless telegraph, of the mechanization of heavy and laborious work, and about the progress of chemical technology.

The leader of the revolutionary proletariat of Russia, Vladimir Il'ich Lenin, attentively traced the course of the development of science and technology in his time, deeply analyzed the significance of the new discoveries in the field of natural science, and noted the great future of many technical projects and innovations. Among these were the electrification of factories, railroads, and agriculture, progressive trends in metallurgy and metalworking, mechanization and automation of coal production, and much more.

Scientists-Marxists correctly connected the possibility of broad use of the promises of scientific and technological progress opening on the threshold of the Twentieth Century in the interests of all the people with the future victory of the socialist system of society.

The formation of scientific and technological forecasting entered into a qualitatively new stage with the appearance and activation of the concept of planned development of science and technology, controlled by the state. The chroniclers of scientific and technological progress of humanity have yet to completely evaluate the worldwide historical significance of the fact that half a century ago, under exceptionally difficult economic conditions, with the absence of any external assistance, in a complex and unfavorable international situation, the Soviet Union began its travel along the path of progress, basing its scientific and technical policies on the Lenin

concept of a planned harmonious development of all branches of science and technology, under the control of a socialist government.

This exclusively progressive principle has successfully withstood the test of history. The experience of its realization rendered a decisive influence on the transition occurring everywhere in the present world (in significantly different social forms) to planned development of science and technology with participation of the government.

It is characteristic and in its way natural, that the first state plan to be unfolded for scientific and technical development in our country - the GOELRO plan - was based on a complex predictive hypothesis developed by a group of specialists under the leadership and with the personal participation of Vladimir Il'ich Lenin. It included the following estimates: resources and requirements of the country, trends in world scientific and technological process, social and economic factors, and the consequences of realization of electrification in a nation which was building communism.

The whole subsequent fate of forecasting science and technology was most directly conditioned by the character and depth of its connection with the practice of planning scientific and technical development, in particular long-range planning.

Analyzing data on the fates of predictions of scientific and technological development in the capitalist countries, foreign scientists also arrive at very symptomatic conclusions. Thus, for example, in a work by the well-known English scientist S. Lilly, published in 1962 under the title "Can Forecasting Become a Science?" [8], the following interesting data are presented (in %) with respect to the reality of predictions of scientific and technological progress advanced at the beginning of the present century (Table 1).

According to this evaluation, the average level of reality of early predictions in our century comprised approximately 80%. Such a degree of reality is quite high for scientifically based fantasy

and, in his opinion, is completely insufficient to permit regarding prediction as a science. Lilly sets the problem of increasing the accuracy of predictions of scientific and technological progress to 95 or 99%.

Table 1.

Date of predictions	Completely validated (as of 19[5]7)	Will probably be validated	Proved in-accurate	Will probably prove in-accurate	Still in doubt	Calculated degree of success of predictions (A + B + 0.5 E)
1906	46	24	21	—	9	74
1915	28	48	—	—	24	88
1920	38	29	8	3	22	78

After analyzing the basic factors connected with this problem, Lilly draws the following conclusion, in our view completely accurate: "Technological forecasting should be an important element to assist in planning the future.... At the same it is a fact that planning alone can make this forecasting itself more practical."

In accordance with contemporary presentations, the forecasting of the development of any object is regarded as specifically deduced information about the future. The content and degree of validity of such forecasting information is determined by the following: historical experience accumulated by humanity; the requirements, knowledge, and conditions existing at the contemporary stage of development; and the possibilities whose realization depends on future generations. The development of the problem of forecasting has a scientific character only in the case when its theoretical structures are based on specific trends revealed by the creators of scientific and technological progress — economists, socialists, and students of science — and in the optimum case, on actual laws of development, if moreover it is dictated by the real requirements of society and takes into account the objective possibilities of scientific and technological progress for the given specific social conditions.

The general logical diagram for the development of forecasting conclusions can be presented as follows:

$$(Z \vee G \vee F) \rightarrow P,$$

where Z is the totality of presentations on the laws and trends in development of the object of forecasting; G is the totality of scientific hypotheses and specific ideas with respect to the future possibilities for development of the object and its varied connections; F — the totality of presentations on factors determining the need for development of the object and on conditions which will stimulate or impede its development; and P shows the forecasting conclusions and assumptions implied by the indicated logical prerequisites.

In our country the scientific direction which is developing the general logical and procedural principles of forecasting and generalizing the laws of the process of developing predictions is called prognostics* [9].

The methodological framework of Soviet forecasting is made up of the scientific categories of materialistic dialectics and, primarily, by the principles of objectivity and regularity of development, the principles that the real world can be known and is inexhaustible.

Forecasting is the theoretical basis of the scientific study of the future. Its basic concept is, naturally, the concept of the prediction of statements or conclusions [10]. Proceeding on the basis of the principles outlined above, we regard it as advisable to formulate a more general definition of forecasting in the following wording. A forecast is an argumentative assertion regarding the future state of an object and its intermediate connections which was previously unknown and is not as yet supported by direct observation. This assertion is formulated on the basis of scientific theory as a conclusion from the totality of specific presentations on the laws

*In international practice the term "futurology" is also used; however, the methodological principles of this direction of science are essentially different from those used in Soviet prognostics. [The term "forecasting" will be used throughout the translation — Translator.]

and trends in development of the object, hypotheses and ideas with respect to future specific possibilities of development, and also concerning certain requirements and conditions of development of the object subject to forecasting.

In relation to a general field of prediction, the forecasting of science and technology is a specific area of scientific research finding its basis in the theories formulated from the study of science itself.

Experience in contemporary scientific and technological forecasting permits us to formulate the following definition: *scientific and technological forecasting is the probability evaluation of the possible paths and results of the development of science and technology, and also the resources and organizational measures required for their achievement* [11].

Contemporary scientific forecasting is expanding the region of its applications, replenishing and innovating the arsenal of methods of forecasting future science and technology. Forecasting is taking on the character of systematic analysis of trends and refinements of evaluations of perspectives. Forecasters, working from known objective laws, trends, requirements, and conditions for the development of science and technology are striving to formulate the possible alternatives of this development and to provide a basis for selecting its future path. Here forecasting is the more successful, the more organically it is connected with planning of scientific, technological, social, and economic development.

A generalizing feature of contemporary forecasting is its system character, taking into account both the changing nature of scientific and technical innovation (the variety of connections and the scale of consequences) and also the rapidly renewed initial requirements, stimuli, and conditions for development of science and technology.

At the same time it should be noted that scientific forecasting is still in the formulation stage. There is an active process of

improving forecasting methods. Criteria and evaluation parameters are subject to checking in real life. Development is underway of methodological problems of forecasting in order to simplify the theoretical principles and to increase the practical effectiveness of forecasting science and technology*.

2. A struggle with the future or a struggle for the future?

The question formulated in the heading above is by no means rhetorical and the answer is not self-evident. A number of important methodological problems of contemporary forecasting touch upon this problem.

In the practice of forecasting the flow of bourgeois predictions is an old feature; it is sharply stained with the spirit of fatalism and permeated with the idea of the weakness of man and society in the face of increasing complexity of development trends. One example of predictions of this type (the prediction of the Adamsses) we discussed in the previous section. Also known are plans to close the Ural Bureau of Patents - plans developed at the beginning of our century - on the basis of the forecast which indicated that all of the important inventions had already been made [14].

In our time predictions in a similar spirit are being formulated on the basis of data about the reduction in the number of newly released medical preparations, the reduction in the number of patent applications with respect to the number of scientists and engineers, and in particular, in consideration on the thousands of dollars of appropriations allocated to research and development [14]. "Having discarded the theological concept of a divine order, we are prepared to accept a different type of fatalism - the totality of trends," wrote Professor Francois Atman with regard to an American forecast for the year 2000. "This new fatalism must have the same oppressive effect on the human spirit, leaving almost no possibility of escape,

*See, for example, works published in 1967 [12, 13].

especially since the developed trends are fortified by statistics and by complex calculations which are regarded as purely scientific" [15]. The French scientist G. Lascault summed up these modes in 1966 in the article "Dangerous Future" in the following words: "But dreams about our society lead to disorder, desperation, and tyranny, or at least to ruin of our planning" [16].

The American theoretician of strategic exploration and forecasting, V. Platt, arrives at the same positions from another direction. Analyzing the important question of the factors which hamper forecasting, he writes: "Such factors include revolution, floods, hurricanes, poor harvests, new achievements in the use of atomic energy and guided missiles, anticolonialism, inflation.... Here the future emerges as our active enemy" [17].

Soviet forecasting stands on positions which differ in principle with respect to the future. Scientifically based forecasts serve, in our opinion, to disclose and objectively evaluate real prospects and possibilities of development. If development trends emerging in the course of accomplishment of plans or evaluated by forecasts are recognized as unsuitable for a scientifically controlled society, the decision to alter these trends is exactly as valid as the decision to select one of the possible alternatives of the predicted development.

Resting upon a unified state scientific and technical policy and utilizing the advantages of planned development, Socialist society undertakes all measures necessary for achievement of the most promising goals. Under these conditions the future is not regarded by us as an enemy, but as a true and reliable ally.

In moving to long-range forecasts, researchers encounter the problem of the so-called "general limit of science." In our opinion, if we do not consider such an alternative as global nuclear-hydrogen war (we are firmly convinced that it can and will be avoided!), then in a search for an answer to the stated question we should turn to examination of the influence of the future fate of scientific progress of three basic groups of factors:

- a) the social conditions of development and the character of utilization of the results of scientific and technological progress;
- b) the question of the limits of development of certain branches of science and technology imposed by nature (resources, requirements, capabilities);
- c) internal contradictions in the development of science.

Social conditions render an exceptionally important influence on the tempo, direction, and character of scientific and technological process. Acute social contradictions accompanying scientific and technical progress in the capitalist countries have an unquestionably negative effect on the tempo and nature of the development of science. This may appear in the future as a slowing of scientific and technological progress in certain countries and thus render a certain inhibiting effect on the general course of the development of world science. However, the rapid development of science and technology in countries with planned management of the economy — a group which includes an ever more significant part of the potential of scientific and technical progress — provides a basis to consider that the existence of a "general limit of science" is, for practical purposes, impossible.

If we speak of the limits of development of science imposed by nature, it is appropriate to note the following. Actually, it is impossible to foresee, for example, the approach of a time when the level of output of a number of types of mineral resources will not grow, but will be reduced.

This, naturally, will influence the scales of the corresponding sciences. However, in place of the mineral resources there will be an incomparably greater introduction into practical useage of their natural and artificial "substitutes," many of which will turn out to be actually more effective.

Limits imposed by nature (working from the laws of climate and the material cycle in the biosphere) are known — for example, limits on the scales of using thermonuclear reactions for purposes of power.

This will stimulate the solution even without an acutely imminent problem of deeper and complex study of the laws of the planet and the biosphere, leading to intensive use of different sources of energy which will "enter painlessly" into the terrestrial material cycle.

Thus, while in time there may occur a damping of the tempos of development of individual branches; in scientific and technological progress as a whole this process will be accompanied by explosive development of many other, newly appearing branches of science.

Now as regards the internal contradictions of the development of science, which in the opinion of a number of foreign theoreticians are capable of leading to retardation or even "self-extinction" of scientific progress. This is the basis, in particular, of the so-called theory of saturation - i.e., the saturation of sciences in proportion to their development.

We shall not pause to consider the very numerous works of sociologists who are frightened by scientific and technological progress and its social consequences in a world of class contradictions, and who for this reason are proponents of the substitution of an idyllic rural life for progress in science and technology [Bardet, 18]. We shall cite only works which are undoubtedly authoritative in the field of competence of the authors. The British State Minister of Education and Science, Lord Bowden, in 1965 published two exhaustive articles considering the "limits of growth" of science [19]. He ascertains that the present trends of rapid growth in science "must be changed sharply and suddenly."

Forecasting the development of science in the future, Professor D. Price put forward the proposition [20, 8] that the law of exponential development will be operative for no more than 30 more years. Then, after two more periods of doubling (in the general case also 30 years) the curves which characterize the active development of science (Fig. 1) will separate evermore noticeably from the ideal curve of "pure exponential growth," asymptotically approaching a determined "saturation limit."

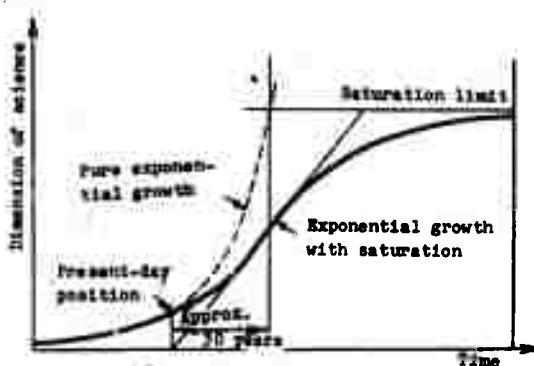


Fig. 1. Saturation curve.

In nature a number of phenomena are known which develop along such a "logical curve." This always happens when development occurs in the presence of specific logical limits and actual factors which limit the maximum dimensions of an object. There are also indices of this type in the sphere of science. An example is the growth in the number of scientists, which cannot, naturally, exceed the population (or more exactly, some definite part of it). In the general case development here occurs in such a way that the higher the achieved level, the slower the rate of growth of the given index.

Is it possible that a similar type of particular case of development can be extended to science as a whole and all the more to science as a system of knowledge?* We shall turn to the arguments of the proponents of the saturation theory.

Predicted changes in the nature of development of science are connected by partisans of this theory exclusively with the so-called "internal repressive influences." Among these the most important are:

- 1) the rapid growth in scientific information, which in many cases already exceeds the capability of human perception. The need for appearance in the future of abstracts of abstracts, and possibly even "abstracts cubed";

*We shall note in passing that in view of the regularly accelerating growth in the level of equipment available for the labor of the people of science, the measures of their numbers accepted today are incomparable in large time scales.

2) the negative effect of the ever narrower specialization of scientific workers: "Things are reaching a point where in the future they will know everything - about nothing";

3) the need for excessive lengthening of periods of education for individuals preparing to take a place in the leading ranks of science: "The more able the man, the longer he must study";

4) reaching the limits of the capability of the human brain for generalization;

5) the "exhaustion" of the possibilities of science itself as such in proportion to the degree to which it exposes the secrets of nature.

On the strength of these considerations the authors of works in this vein express a completely restrained -- not to say pessimistic -- view of the future of scientific progress. In 1963 in his principal work "Little Science, Big Science," V. Price wrote: "Within the lifetime of a single generation science will have to turn away from the traditional exponential growth and approach a critical point, marking its transition to senility"* [21].

A similar concept has been formed under the influence of actual experience of the past. However, we are convinced that the accomplishments of science in the last decade, in particular those connected with the vigorous development of cybernetics, permit us to recognize the fear of a limit of development of science as a system for producing new knowledge to be groundless, although actually existing difficulties and problems are reflected in a number of the arguments given above. We shall examine these in the same order.

First of all, the problems of the mechanization and automation of many types of scientific work, including the search for required scientific and technical information, have now successfully moved out

*In his following works the author introduced a refinement to the effect that such conclusions relate to the need for radical change in existing organization and forms in which contemporary science is developing. This is essential.

of the experimental stage. Also on the current agenda are problems of the data-logical systems intended to assist the scientist in processing the extensive volume of information in the area of classification of information, determination of its novelty, reliability, essential importance, etc.

Secondly, the vigorous development occurring at present in the development of sciences standing at the boundaries of frequently very remote and specialized disciplines instills confidence that "narrow, compartmentalized" specialization is by no means the high road of contemporary science. The more the secrets of nature (particularly of living nature) are uncovered, the more closely interconnected various sciences become, and the more that barriers, boundaries, and blank spots between them are liquidated, the more widespread will be specialists with a broad profile.

Naturally, in view of the need for profound development of certain problems and areas of science the future will see retention of the need to concentrate forces on their constant study. But the radical changes in the technology of obtaining and transmitting information, the existence of common methods and approaches of scientific work, and the widely accepted necessity and possibility of mutual enrichment of various sciences serve as important guarantees against the "closed shop" system of specialization of scientific people.

Now specialization can be considered as a typical misfortune of the past (and also the present and future) stage of the development of science, when the volume of problems faced by humanity was excessively great in comparison with the physiological capabilities of the technically inadequately equipped human brain.

In our day in connection with the enormous successes in cybernetics, electronic computers, informational, measurement, and other types of technology, we note a trend of leading development of equipment available for the labor of scientific people. We will note that the realization of these progressive trends once again imposes a

requirement for significant improvement in the scientific organization of labor in contemporary science.

Regarding the third point, we have already set out on the road of introducing basic changes in instructional procedures, directed toward improving its quality and shortening its duration. The central features of this readjustment of education can be presented as follows:

bringing instruction closer to the demands of practice (in the broad sense of this word, we include both directly applied problems and also serious scientific theoretical problems);

broad practical use of cybernetic teaching machines, which permits maximum individualizing of the educational process and increasing its effectiveness;

a radical reexamination of the content of courses presented to the students, reducing a number of them to the form of generalized reference material;

the formulation and introduction into practice of the study of specific scientific disciplines, wholly directed toward providing future specialists with a correct understanding of the general process of the development of science and technology, a creative understanding of the contradictions, motive forces, and laws of scientific and technical progress as a whole;

ever broader utilization on all stages of education of methods designed to inculcate habits for the independent obtaining of new knowledge, i.e., study by means of algorithms of scientific generalizations, and not with information at its lowest level.

Regarding the fourth point, the requirement for reinforcing the intellectual capabilities of the human by means of new technical equipment has been realized by contemporary science. Considerable forces have been concentrated on solution of this problem. In the last 15-20 years the operating speed of electronic computers has grown by 10,000 times. The creation of machines with operating speeds of hundreds of thousands and even millions of calculations per second is on the agenda. It is felt that a billion operations per

second may not be a limit for automatic systems of the future. Along with operating speed, the logical capabilities of the machines will grow. The possibility of carrying out such types of intellectual labor of the scientist as proving complex theorems, deriving formulas, construction of generalized theories, etc., on electronic computers has been proved. Major attention is being directed toward the solution of problems of interfacing the human being with the electronic computer.

When speaking of the essentially unlimited possibilities for development of technical equipment for mental labor, at the same time we should not forget the existence of the huge resources for improving the work of the human brain itself. In any case the joint work of improved cybernetic devices and well-trained and well-equipped humans controlling them will prove in the near future a colossal jump in the growth of the intellectual forces of humanity.

And, finally, the fifth point - the exhaustion of problems for science, the so-called "scraping the bottom of the barrel." Nature is infinite, knowable, and inexhaustible - such a scientific philosophy is a true one, which can be confirmed by all the historical experience of human knowledge.

Certainly, as science and technology progress as a whole, individual branches of science will significantly depart from ideal growth curves in their own development. In the future, as has occurred not infrequently in the past, certain scientific disciplines may undergo periods of retarded development. This is reflected on the nature of the corresponding curves. Certain of them may go into a decline.

We will permit ourselves to assert the opinion that such fate will be suffered first of all by the pseudosciences - theology, astrology, hypnosis therapy, and so on - whose functioning in a number of countries is an excessively prolonged historical incident.

But what is the meaning of a similar phenomenon for sciences which desire this high designation, and how can it be accomplished?

In our view such a phenomenon in the course of development of a specific branch of science attests at least to one of two circumstances: either there was a sudden maturation in the given branch of knowledge for transition to utilization of qualitatively new methods and scientific ideas, or the practical requirements for further acceleration of development of this area of science underwent a noticeable decline.

In the first case we can predict that sooner or later the new methods and scientific and technological equipment required for a given science will be found. New fruitful scientific ideas will appear. Probably they will be called "cardinal," "revolutionary," or even "brilliant." Sometimes the authors of such ideas may turn out to be people far removed from the traditional methods and views governing the given branch of science.

However, the main and determining factor will be that the development of such cardinal scientific ideas and methods will go further, the greater the united creative labor of collectives, harmoniously combining and utilizing the varied individual capabilities, knowledge, and views of many talented researchers.

In the second case, there will occur a natural contraction of the scales of operative branches of science and of the appearance of new vital requirements (both practical and theoretical) able to revive it once more and, as a rule, on a new scientific and procedural basis with respect to the "obsolete" scientific discipline.

In this regular process, both at present, and in particular, in the future, the basic sciences - mathematics, physics, chemistry, biology, and physiology, and others - will play more of a "fertilizing" role. It is precisely these sciences which guarantee a general accelerated character of development to scientific and technological progress.

The general character of scientific progress which is predicted for the future can be illustrated by the following diagram (Fig. 2),

which has a hypothetical character. Moreover, as yet we are not able to attach it to qualitatively determined coordinates "time - index of scientific progress."^{*} However, for all its obvious conditionality, it seems to us that this diagram reflects the dialectic side of the process of development of the sciences in their interplay with practical affairs and with each other.

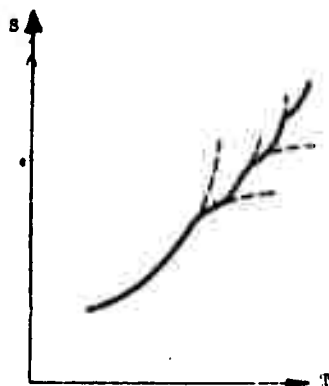


Fig. 2. Hypothetical curve of the general path of scientific development.

3. Concepts and elements of the theory of scientific and technological forecasts

At present various patterns of forecasting are known: resources, public requirements, industrial potential, the development of social conditions, demographic, complex forecasts of the development of economics, and others, all having a tendency to be aggregated into a mutually connected system of presentations.

Scientific and technological forecasts touch directly on the system of forecasts of social and economic processes. They can, with complete justification, be treated as a subsystem of it, retaining their own specific features which ensue from the uniqueness of the

^{*}The generalized indices of the development of science used for such long-range predictions will, obviously, have to be essentially different from the indices used during analysis of the development of science on the contemporary stage.

objects, purposes, and methods of forecasting.

The close connection of scientific and technological forecasting with economics, and through it with sociology, is expressed not only in the use of elements of social and economic analysis during evaluation of the initial positions of forecasting, in the course of forecasting, and during selection of the resulting variants, but it is reflected first of all in the fact that the scientific and technological process to be predicted is a determining factor of the effectiveness of the process of public production.

The essential differences of scientific and technological forecasting from the prediction of economic development are found on the level of the differences between the concepts "science and technology" on the one hand and "industry, agriculture, medicine, etc." on the other. The structure and relationship of the elements which are included in the region of true scientific and technological predictions are shown by us (in accordance with the ideas of V. G. Gmoshinskiy) on Fig. 3.

The typology of scientific and technological predictions is completely representative [9, 22, 23]. For example, it is possible to classify forecasts of science and technology according to scales, level of complexity, lead time, by regions, etc. It is essential here to distinguish the scientific forecasting of such mutually connected objects: the development of science as a system of knowledge; the development of an organizational system of science; the development of technology - in which, in turn, we single out the level of industrially mastered technical equipment and the level of new technological developments [24].

Cases of the forecasting of scientific discoveries represent a very rare phenomenon. Much more frequently scientists foresee the ripening of a "breakthrough" on one or another segment of the scientific front; experience and intuition permit them to judge the promise in the interaction of various scientific areas, of their cross-fertilizing by ideas, methods, and new capabilities. These

predictions fall in the sphere of competence and responsibility not of the student science himself, but primarily of one or another group of specialists in the sciences, whose experience forms the basis from which the student of science/forecaster operates. Scientific and technological forecasting has developed and uses special procedures of collecting, analyzing, and synthesizing of a similar type of objective and intuitive information, supplementing it with special information of an organizational and scientific character.

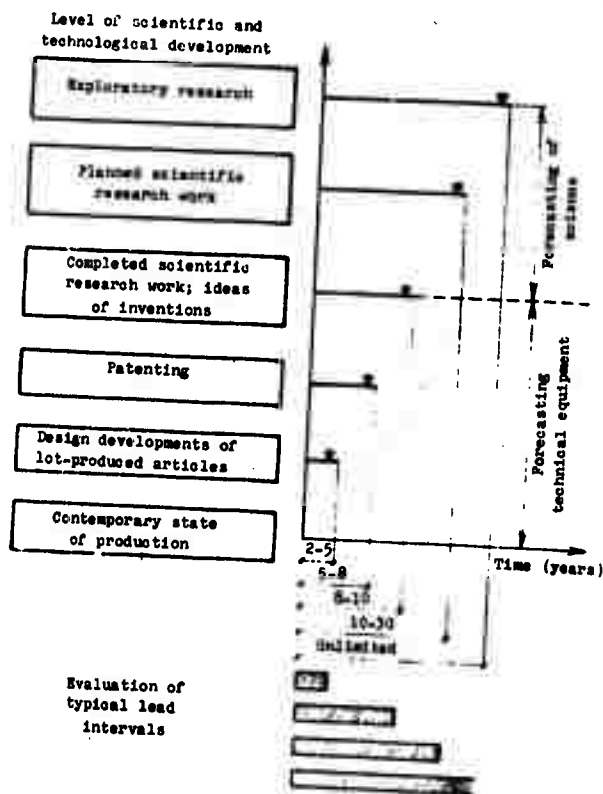


Fig. 3. Structure and relationship of elements included in the field of scientific and technological forecasting.

The connection between different objects of forecasting has a complex dialectic character, in view of which in practice such a division frequently proves to be very tentative. The development of scientific ideas can lead to the formulation of new views of future technological equipment, while long-range forecasting of the direction of development of technology requires, as a rule, consideration of

trends in the development of science as a system of knowledge.

We shall outline here the functional classification of scientific and technological predictions which is, in our opinion, the most interesting. Its basis is the idea ensuing from the accepted definition of prediction as a complex of mutually connected evaluations: goals, methods for achieving them, and resource requirements.

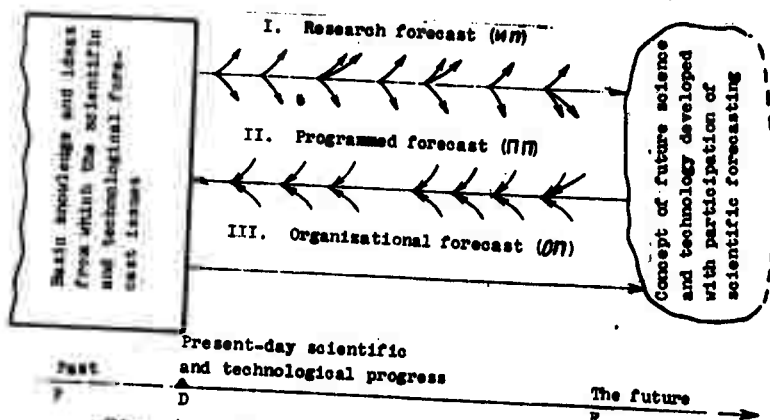


Fig. 4. Functional classification of scientific and technological forecasts.

Forecasting of the first type, based on known trends and laws, on the accumulated experience of specific sciences, is intended to expose and formulate new possibilities and promising directions in scientific and technological development. In scientific forecasting, this type of prediction (Fig. 4) is called *research forecast* (NM)*. Its most difficult, critical, and most frequently final phase is evaluation of the hypothetical result or, generally speaking, of the significance of the possible variants of development. Information thus obtained is an essential part of the concept of future science and technology formulated with the participation of scientific forecasting.

*May correlate with "exploratory forecasting" per E. Jantsch - Translator.

The second type of scientific and technological prediction we will call *programmed prediction* (ПП)*. It proceeds from known public needs, trends, and laws of scientific and technological development, and also on the basis of data obtained by ИП. It is intended to impart to these data an applied character: to formulate a program of possible paths, measures, and conditions for achieving goals and solving problems of the development of science and technology. Formulating an hypothesis concerning the possibilities of mutual influence of different factors which are promising for the given conditions (see the direction of arrows on Fig. 4), ПП (most often on its concluding stage) strives to give an evaluation of the hypothetical periods and sequence of achieving different possible goals. Thereby ПП completes the formulation of the possibilities of development begun on the ИП stage.

It is appropriate to note that where ИП has as its object contemplated internal possibilities of scientific and technological development, ПП deals mostly with problems arising because of practical requirements (engineering, medicine, agriculture, etc.) and with the consequences to be expected from this.

Thus, a forecast made up of the prospect of development of cybernetics, trends in the growth of operating speed of electronic computers, an increase in the volume of their storage and with expansion of the range of logical capabilities — this is a typical research forecast. Its basic goal is to uncover the gamma of the prospects which are possible in principle. On the other hand, a forecast which ranks along the axis of future time a series of most important expected events in the progress of cybernetics and computer technology, fixing the most promising connections of this process and possible paths for its realization — this is a typical programmed forecast.

*In foreign scientific forecasting, a prediction of a similar but not completely identical type is also called "normative" [Erich Jantsch, 22].

An *organizational forecast* (ОН) is based on knowledge and ideas about the general laws and trends of the development of a science (as an organizational system), including the obtained ИП and ПП. It proceeds from the basis of presentations about the availability of economic resources and the accumulation of scientific potential [25]. The ОН is intended to formulate the fundamental hypothesis of development of the complex of organizational aspects of the science, to give an evaluation of the prospects for growth of the scientific potential of the country or of a branch in the period of the forecast.*

For example, a characteristic example of ОН might be the prediction of the imminent changes in the number and structure of scientific cadres, including scientists with high qualifications, scientific workers, engineers, and auxiliary workers who will be needed to guarantee successful development of cybernetics in the next 10-15 year. Usually the most difficult and critical phase of ОН is evaluation of the hypothetical dimensions of the required financial support for different programs of research and development.

In combination the three types of forecasts delineated above mutually supplement one another, making available to those responsible for making decisions an especially valuable *data system*. We will note, however, that the measure of "controllability" of the path of realizing the forecasts, the possibilities for organizational and economic factors to influence them directly, and correspondingly the possibilities of predicting the path of development, are essentially different. In this respect ОН > ПП > ИП.

To logically complete the example developed above, we shall point as an illustration to the possibility of obtaining a complex forecast of the electronic computer of the future. In its time the tube electronic computer of the first generation was replaced by the semiconductor electronic computers of the second generation. Regular

*We should note that the absence in forecasting of clearly separated predictions of this type would significantly lower the complexity of the forecast evaluations, hampering their subsequent practical utilization.

replacement of the latter has now begun with electronic computers which are characterized by integrated circuits, high operating speed, and a number of other important criteria and essentially new properties. A scientifically based forecast of electronic computers of the fourth, and, partially, the fifth generation should give an evaluation of the relative significance of the different events necessary for their creation, ideas about the probabilities of completion of such events in time, and also a tentative evaluation of the magnitude and structure of resources relating to this problem.

In a complex forecast of such type an important place is occupied by argumentation of organizational and technical measures: the exclusion of a number of intermediate stages of development, parallel realization of certain other events, the use of new capabilities of the sharply increased "intellectual power" of electronic computers (for example, combining of computers, the creation of uniform computer systems, territorial nets of computer centers, etc.). On the basis of these data it might be possible to attempt to plan the strategy of accelerated achievement of a higher level of scientific and technological progress in this important field.

Each scientifically based forecast contains, as it were, an alloy of times: the past (development trends), the present (availability of resources and ideas), and the future (requirements and possibilities). Depending upon which period in the future the predictions are being made for, they have different character — they differ significantly in reliability and are used differently in the practical matter of making decisions.

In scientific and technological forecasting, it is possible to single out with sufficient clarity three technical intervals of lead time, which we have called [1] "echelons of forecasting." Forecasts of the first echelon are usually calculated for a period of up to 15-20 years. With the formed tempos of development, in the indicated period the following will occur: one-two doublings of the total number of published scientific works, doubling of the quantity of technical equipment for production, termination of the effective period

of the majority of existing patents, etc. A very important circumstance is the fact that this time interval will contain typical and existing trends toward a reduction in the period during which facts, phenomena, and principles established by science move from the mental sciences into the applied areas and from there to developers and, after experimental and industrial checking, to the stage of mass production utilization of technical equipment based on them.

Another essential factor is the circumstance that a new generation of specialists will enter into the front line of scientific and technological progress over this period of time; at the end of the period they will comprise an absolute majority with respect to those who were participants in the work at its beginning. In such a time segment there will have occurred in past years two doublings of the number of scientists and, at least, three doublings of the number of engineering and technical workers (an increase in number of 8-10 times).

Forecasts of this echelon ordinarily are issued on the basis of the capabilities for scientific and technological progress which are fully determined at the present (at least theoretically). They include not only qualitative (content), but also, as a rule, quantitative evaluations. In a society with planned control, these forecasts directly join forecasting with the practice of prospective planning (see Fig. 5).

Forecasts of the second echelon are calculated for a period of 40-45 years into the future. This lead time is characterized by a doubling of the majority of concepts, theories, and treatments accepted in contemporary science. During this period there will be a doubling of world population (~35 years) and again complete replacement of the generation of creators of scientific and technological progress (~40 years - the evaluated duration of the period of independent creative activity of a human).

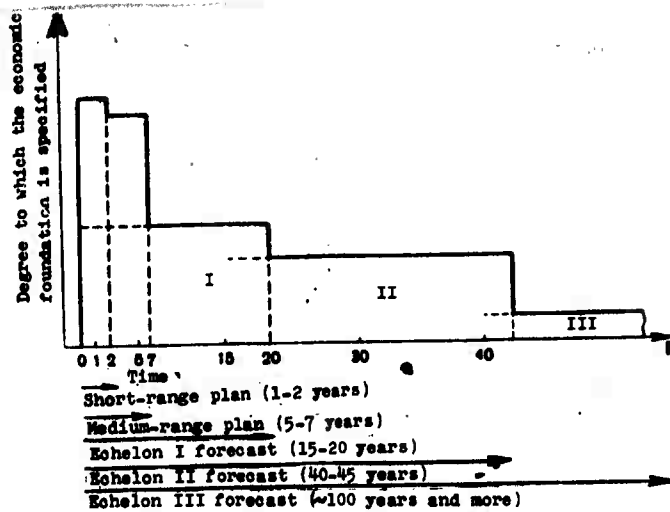


Fig. 5. Relationship of the range and degree of economic validity of scientific and technological forecasts with different lead-time intervals.

In forecasts relating to this period (the first decade of the 21st Century), quantitative evaluations yield their place ever more frequently to qualitative. The visible constraining limits of such forecasts are frequently considered to be not the economic capabilities, but ordinarily only the fundamental laws and principles of natural science which are crystallized at the present moment. At the same time a scientist developing a forecast of such range cannot limit himself to presentations falling within his particular branch of knowledge (these presentations will be essentially changed), but must base his work on a broader system of scientific presentations.

Forecasts of the third echelon are oriented toward a term of up to 100 years and sometimes even further into the future. As a rule, such forecasts have a purely hypothetical character. Realizing that the creators of scientific and technological progress in such a distant future will proceed on the basis of a system of scientific presentations worked out by them and which is unknown to us in many of its essential aspects, the contemporary forecaster in this case relies more on Weltanschauung and creative fantasy than on an orderly system of presentations of natural science.

As a rule there are no quantitative evaluations here, and the qualitative evaluations and assumptions are limited only to the frameworks of the most general laws of logic, Weltanschauung, and natural science.

Any forecasts always contain elements of conjecture. Life experience, the achievements of science, and the possibilities and requirements of practice introduce significant corrections into them every day. Their fate is influenced to a decisive degree by the development of the social life of society and by the discovery of new secrets of nature. All of this noticeably determines the debatable nature of long-range forecasts of the third echelon.

If the authors of forecasts of scientific and technological progress did not limit the span of their dreams to the defined frameworks of formed scientific presentations on the development of society, economics, natural science, and technology, for us their conclusions would be deprived of conclusive force, i.e., would lose their scientific value. A survey of the literature concerned with scientific and technological forecasting makes it possible to point out three basic groups of such presentations, having a determining influence on the degree of reality of a scientific forecast: a) scientific ideas on the social and economic advisability and the economic feasibility of realizing the predicted scientific and technological decisions; b) the laws and principles of natural science, a considerable part of which are frequently called, in the keen expression of George Thomson, "the principles of impossibility"; c) the most common laws of the nature and development of society, usually formulated in the form of the principles of the Weltanschauung of the scientist.

The authors of forecasts in the first echelon strive, as a rule, to consider all of these three groups of "limits." This explains, to a great degree, their relatively high accuracy. With transition to forecasts on the second echelon the authors must, to a certain degree, remove themselves from conditions imposed by economic categories, while in forecasts of the third echelon they consider also the

historical relativity of a number of presently accepted positions of science.

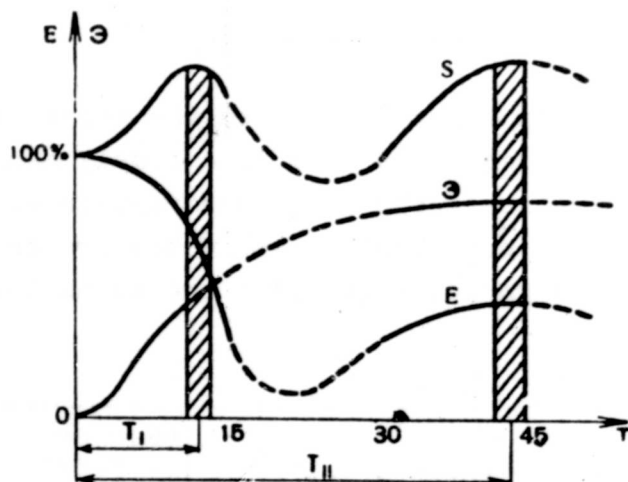


Fig. 6. On the selection of an optimum lead-time interval.

Forecasts always have a hypothetical character. In drawing conclusions about the future on the basis of analysis of information on the past and present, the forecaster cannot take into account many essential factors which will arise and will influence the development of the predicted process in the future. Here the long experience of science indicates that the more successful it is in solving problems, the greater the quantity of new problems which arise before the researchers.

In the relationship of programmed predictions there is known a statistical observation, based on American experience of scientific and technological forecasting [22]. According to these data, the relative accuracy of $\Pi\Pi$ as a function of lead time has such a form (see curve E on Fig. 6). The characteristic trough in the curve, occurring in the period of the second 15 years (second echelon of forecasts) is explained by the fact that in the first 15-year period the "incubation period" of the majority of initial scientific and technological ideas was completed; many circumstances and possibilities foreseen earlier have arisen. The somewhat increased accuracy of the subsequent segment of the curve is explained by the fact that on the more distant (~ 40 years) perspective the forecasters are interested, as a rule, only in scientific and technological problems

which are directly connected with factors which are operative over a prolonged period — with the utilization of resources and the possible social consequences.

On this same diagram there is plotted the curve of the change (3) of effectiveness of decisions made in a timely manner on the basis of the forecast information [26]. The construction of the summary (E + 3) curve S makes it possible to assume the presence of two optimum intervals of range for scientific and technological forecasts.

Table 2.

Areas and objects of forecasting	Required depth of forecast evaluations, years	Depth usually achievable, years
Volume of accessible natural resources.....	50 and more	25-35
Innovations and technical equipment with strongly expressed social consequences (automation, mass means of communication, transport, city planning, etc.).....	30-50	5-10
Nuclear energy.....	25	10-12
Space programs.....	20-30	7-10
Armaments.....	20-25	7-10
The national economy.....	20	5-7
Mass and large-lot production of technical equipment (for example, in electronics, chemistry, etc.).....	10-20	5-7
Production of new consumer goods.....	5-10	3-5

Our summary evaluation of the optimum range of lead-time intervals, formulated on the basis of all the data examined above, is as follows: for specific forecasts with predominance of evaluations of applied scientific and technological decisions, $T_{\text{онт}} = 10-15$ years; for more generalized forecasts of scientific and technological development in connection with the existence of natural resources and with social and demographic processes, $T_{\text{онт}} = 35-45$ years. Naturally, different areas and objects of forecasting will require a different depth of prediction. The ideas of world-wide forecasting [22] on this problem are presented by us in Table 2; they include

consideration of the latest data. From the information given in this table it is evident that there is a significant break between the required and presently achievable depth of forecasting. The consequence is the urgency in modernizing methods of scientific and technological forecasting.

CHAPTER II

INFORMATIONAL AND LOGICAL PRINCIPLES OF FORECASTING

1. Prediction potential of scientific and technological information

Science is a world of uniqueness. While it is called upon to produce new knowledge, science in principle does not admit there petitions, rubber-stamps, and rigidly unified norms. All of its essential phenomena are, as a rule, unique with respect to scientific and technological creativity. The words of V. I. Lenin are especially valid: "...old situations are not repeated in their previous form".

This means that very frequently specific data on the experience of the functioning of a science and its results are not comparable. Actually, in what scale would you measure and compare the discovery of the 104th chemical element - "kurchatoviya" - and the Mossbauer effect?

In searching for characteristics of development which would be comparable in time and for different branches of science we arrived at the conclusion that there is promise in the approach to scientific research activity as to a unique information process. From this general informational point of view science can be regarded as a complex dynamic information system created for the collection, analysis, and processing of information in order to obtain new truths, new practical applications.

*V. I. Lenin. Complete collected works, Vol. 38, p. 134.

It is widely known that the volume and character of information collected by a researcher, the methods of the analyzing and evaluating it, the forms and trends in the utilization of information, and the degree to which the flow of information is enriched with newly obtained data and generalizations - all of these determine to a significant degree the level and promise of any research. Of particular importance and specific complexity is the data base in scientific exploratory forecasting studies.

The range of the data base for such studies and developments is exceptionally broad: from preprint and claim regarding an invention or discovery to the report of the launching of a new spacecraft. In manuscripts, printed works, abstract journals, patents, certificates of discovery, in the registration documents of dissertations, statistics on the growth of scientific cadres and other such symbol systems there is reflected and specifically materialized the living course heuristic thought; the many-sided experience of organization and functioning of science is reflected with various degrees of completeness and reliability.

In view of the regular succession of stages of scientific and technological progress, the thought of G. Leibnitz always was and always will be valid - "The present is fraught with the future." Here the future arises and is formed not as a simple molding from the past and present, but as a higher form of manifestation of dialectic tendencies of development. Its features can be manifested only on the basis of manifold and careful analysis.

This is why one of the essential prerequisites for success in forecasting is the selection of the appropriate data base.

Scientific forecasting makes broad use of the important fact that the process of scientific and technological development generates a genetic succession between different types of information sources.

The experience of systematic industrial utilization of specific technical equipment is preceded by 5-7 years of work on designing and

manufacturing a broader collection of machines. The latter, in its turn, lags 3-5 years behind invention, establishment of claims, patents, and authors' certificates of invention. In our time, as a rule, technological experience is preceded by experience in scientific development of problems, discovery of new properties, capabilities, operating principles, etc. Preceding the last type of results of science there is only scientific intuition - the totality of hypotheses, assumptions, and guesses of the specialists.

In the process of forecasting, information relative to each of the enumerated types of knowledge is collected and analyzed in connection with the requirements of humanity, society, nature, and scientific and technological progress itself as foreseen (and not infrequently quantitatively determined) for a greater or lesser significant interval. The availability of such a specific basis is an important feature of scientific forecasts, distinguishing them from the groundless "fortune-telling" type of predictions on the fate of the future which are also encountered.

More complete and creative utilization of past experience is one of the most important prerequisites for accelerated tempos of scientific and technological development. Any collection of creators of scientific and technological process at any stage of its activity will generate, accumulate, transmit, and process flows of informational materials reflecting the many-sided experience of resolving problems of scientific and technological development.

These materials are extremely broad in quantity and are varied in the content and form of their presentation. In principle they can be used: a) as the basis for analysis and comparative evaluations of contemporary experience; b) as a direct source of a line of reasoning when making decisions with respect to future development; c) as material for recreating historical trends and forecasting scientific and technological progress in a given area.

In the solution of problems of this type the data base is by no means unique for the development of judgements, but its availability plays an ever more important role.

If we speak separately of two real types of utilization of scientific and technological information, their prerequisite is a generalized property of the massive flow of scientific and technical information - to illuminate the path to the immediate future, i.e., to possess one or another lead-time potential*.

We shall turn attention to the following circumstances.

First. Each document, in view of the specific features of its content and the uniqueness of the fate befalling it, possesses individual properties with respect to the future. There are individual documents for which the value of their contents has been recognized or understood only a decade after their appearance. Many documents will carry information which loses the indicated property within a year of appearance. Therefore the concept of a "lead-time potential" is formulated as generalizing for the massive flow of information.

Second. The considered property depends on the general tempos of scientific and technological development: the higher the rate of renewal of accepted methods, concepts, and technological ideas formed in a given region, the more difficult it is to ensure direct use in the more distant future of the flow of informational materials.

Third. Among the mass of information on the experience of scientific development, designing, and construction, experimental checking of specimens, testing of lot-produced machines, industrial exploitation of technical equipment, etc., scientific information possesses the greatest lead-time potential. It contains information on the experience of scientific research and scientific generalization of the experience of preceding practice. The last stages of scientific and technological progress are usually found within the limits of the lead-time potential, determined for the given region by its scientific researches.

*We developed this problem together with L. P. Smirnov and Ye. I. Levin [27].

Fourth. The concept "lead-time potential" emerges as generalizing also because it is based upon the totality of specific properties of the flow of scientific and technical information. We shall indicate eight such properties which have essential significance for the contextual analysis of massive flows of information.

1. In information flows it is always possible to note their directivity (between objective areas, from one stage of a process to another, from the work of one author to the works of others, etc.).

2. Flows of information can be subjected to quantitative evaluation (rate, acceleration or retardation).

3. Within the flow it is possible to single out characteristic structural components (to note separately and to compare information on the facts of the science, its methods and its concepts, or information of a scientific, industrial, and design-constructural character, etc.).

4. From various types of documentary sources it is possible to form a sequence of documents in accordance with the logical succession of different stages of heuristic activity. For example: $A \rightarrow B \rightarrow C \rightarrow D \rightarrow E \rightarrow F$, where A is the material of systematic questioning of *a priori* evaluations and judgements on the level of intuition; B is material from archives of claims for inventions or discoveries; C represents documents (acts) relating to inventions: patents and authors' certificates; D represents data on experiments and tests; E is the outline of experience in operating actually created technical equipment; and F represents materials of generalizing scientific technical and economic evaluation of branches, etc.

5. The selection of variants and possibilities from the preceding links to the following ones, produced in the course of the creative process, is reflected in each specific sequence of documents. From this follows the property of the chain which can be called lead-time redundancy: * $|A| > |B| > |C| > |D| > |E| > |F|$.

*Another name for this property, proposed by M. K. Petrov, is left redundancy.

6. In producing the selection of variants and making decisions on each stage of the process, the creators of scientific and technological progress form the probability model of the following several stages from the elements of all preceding stages. From this there follows the property: the features and elements of information of any given stage of a sequence of documents is contained in explicit or implicit form and to a different degree in documents of the series of preceding links of the information flow.

7. A logically ordered sequence of documents possesses the property of natural ranging along the axis of the real time in which the process of scientific and technological development is completed. Hence factors, for example, such as the possibility and urgency of measuring "lag" - the distance between the time of formulation of various links of the information chain - become obvious. The most interesting of the types of "lag": $l_1 = t_C - t_B$; $l_2 = t_P - t_C$; $l_3 = t_P - t_B$; $l_4 = t_E - t_P$; $l_5 = t_E - t_B$; $l_6 = t_F - t_A$, where t_A, t_B , etc. - time of dating the respective links of the chain.

8. The student of science does not deal with the process in which he is interested, but only with the reflection of this process in the array of data. This causes the indirect (in principle) nature of informational gages, parameters, and indices of the process of scientific and technological development. The need for constant checking of the degree of adequacy of these indices for the actual process is a consequence of practical importance of the indicated property.

The totality of named properties of flows of information on scientific and technological experience creates practical prerequisites for seeking, developing, and mastering methods of analyzing trends and forecasting scientific and technological development on the basis of massive flows of information containing the required logically ordered sequence of documents. Special attention of the scientist should be drawn to the genetically "earlier" data arrays which carry the embryos of future ideas and trends.

Thus, for example, the general multi-year array of claims to inventions and discoveries can, with complete justification, be regarded as the totality of data of a unique systematic questioning of the opinions of creators of scientific and technological progress. The high degree of interest of the "questioner" in the quality and objectivity of the data, the significant level of individualization and independence of judgement, the stable magnitude and representative nature of the array — all of these qualities (independently of specific judgement of each individual claim) make information stores of this type exceptionally valuable for subsequent statistical analysis.

Such stores clearly manifest that property of associations of activity of which F. Engels wrote in 1890, "that the wills of individual persons, each of whom wants whatever his physical constitution and external, in the final consideration economic, circumstances can bring him (or his inherent, personal, or social circumstances); that these do not achieve that which they want, but are merged into something of an average, to one common uniformly effective [will]..."*.

For example, in the process of a multiaspect analysis on the electronic digital computer "Ural-4" of the total array of Soviet claims to invention in the field of coal combine building, it was possible to obtain a very indicative picture of the changes in trends in construction of these machines (Figs. 7, 8).

The diagram reflects the characteristic fact that under the influence of the data from practical experience and scientific research, based on personal experience, the creators of new machines switched from designing combines with the so-called "wide-grab" operating elements to the use of the more promising principles connected with the concept of a "narrow grab." It is important to emphasize that the redistribution of forces of the creators of the new technology over at least 8-10 years, which is obvious from the given diagram, determined the changes occurring subsequently in the makeup of the technology itself. Here there is a specific manifestation

*K. Marx and F. Engels, Writings, Vol. 37, p. 396.

of the property of a massive flow of scientific and technological information which we called the lead-time potential.

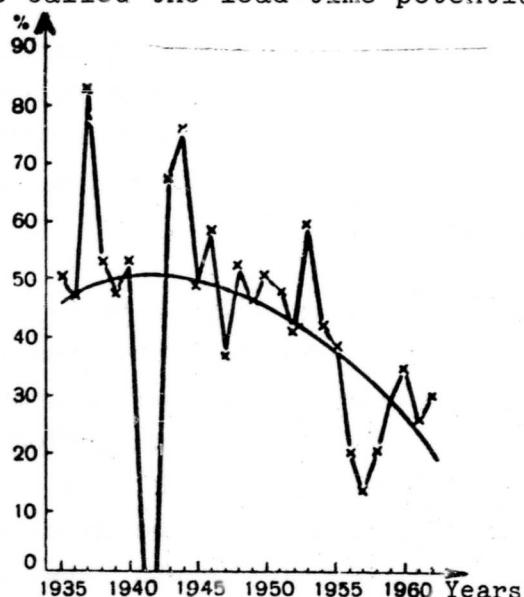


Fig. 7. Dynamics of the redistribution of efforts of creators of new technology (wide-grab coal combines).

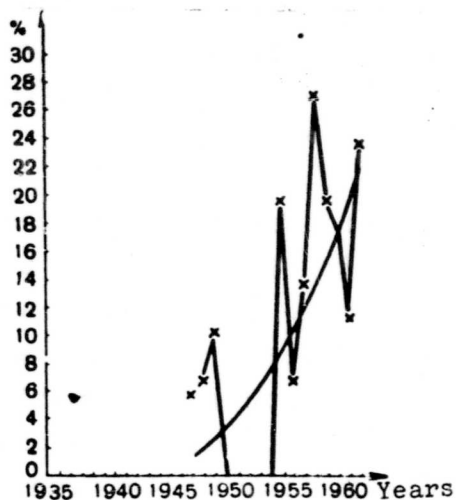


Fig. 8. Dynamics of the redistribution of efforts of creators of new technology (narrow-grab coal combines).

We undertook an effort at quantitative evaluation of the changes in the lead-time potential appearing in a multiyear mass flow of information about experience in mining science and technology. As the

basis we took the complex of information reflected for the years 1935-1965 in the annals of books and journal articles, and also (after 1956) in the abstract journal "Mining." This flow carries information elements of various characters (general industrial information, information on the experience of scientific researches and generalizations, materials on design and construction developments, on the experience of manufacturing and operating technical equipment, chronicles of current events, etc.).

We will recall that in the study of science the general tempo of the growth in the magnitude of flow of information is frequently regarded as an indirect informational index of the speed of development of a given region of scientific and technological creativity. In this case the period of doubling of the total volume of accumulated information is regarded as a measure of the development rate (the greater this period, the smaller the growth rate, and vice versa).

It is natural to assume that any specially constructed index of the structure of the flow which reflects its lead-time potential will vary in accordance with our intuitive understanding of the level of the "scientific nature" of development of the given branch and will be inversely proportional to such an informational criterion as the "doubling period."

The following assumption served as the basis for constructing such an index. The total lead-time potential w_0 for the flow is comprised both of w_s - lead-time potential of scientific information - and of w_T - the lead-time potential of technical information, along with w_p - the potential of industrial information, etc. Each of these components equals the intensity of the corresponding portion of the flow multiplied by its coefficient in the years of the lead (τ_s , τ_T , τ_p) etc.). The lead time for the scientific portion of the flow can be taken as $\tau \geq l\tau_1$, where l is the number of stages of realization of the scientific idea from research to regularly operated specimens. This allowance was based on the assumption that scientific and technological progress will not result in morally obsolete technology.

We used the index of the structure of the scientific and technological information flow represented by $\frac{\Sigma H_{\tau\pi}}{\Sigma H_H + \Sigma O_{\pi}}$, in which the numerator contains $\Sigma H_{\tau\pi}$ - intensity of the part of the flow relating to publications on theoretical and laboratory investigations, while the denominator contains $\Sigma H_H + \Sigma O_{\pi}$ - respectively, the intensity of works on production tests and works on experience in operating technical equipment relating to the same year. In this structural index it is not possible, in the first approximation, to take into account quantitatively the still unknown values $\tau_{\tau\pi}$, $\tau_{\pi\pi}$ and $\tau_{O_{\pi}}$.

Figure 9 shows the data of statistical analysis of a selected flow of scientific and technological information.

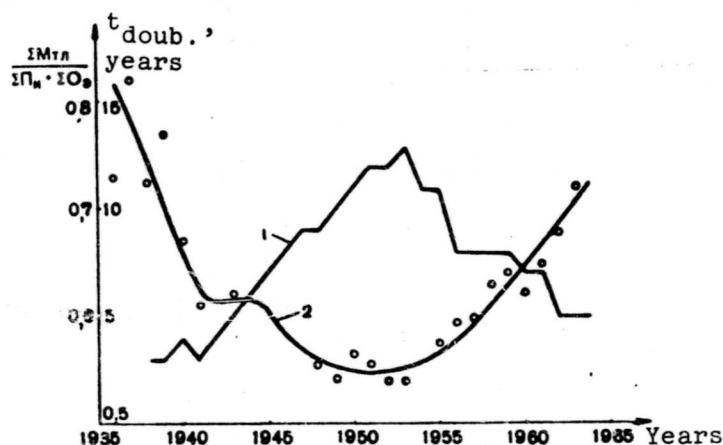


Fig. 9. Diagram of the change in informational characteristics. 1 - Doubling period; 2 - ratio of the number of works of a scientific research type to those of a production-operational character.

Examination of these data brings out the very symptomatic character of the change in the two information characteristics. These data can be treated as indirect informational evidence of a reduction in the tempo of development of scientific research in the war years, and also a delay in the following 7-8 years in their growth rates as opposed to the general rates of development of design and construction work and work on the introduction and mastery of technological equipment. Beginning around 1953-1954 the examined region shows a fairly stable trend toward acceleration of general

growth rates in the volumes of scientific and technological data with a leading character of the growth of the actual scientific component of the general flow of information. The latter circumstance can, in turn, be interpreted as manifestation of a trend toward growth of the overall lead-time potential of the examined massive flow of scientific and technical information.

Naturally, the lead-time potential depends to a considerable degree both on the type of information sources (Fig. 10), and on the sphere of its utilization (Fig. 11) [28].

By their very essence, informational processes penetrate and bind together all regions of scientific and technological creativity. This conditions the predicted potential of those of scientific and technical information - the possibility of analyzing trends and forecasting both on the basis of the examined content of documents and according to the "information signals" (by the characteristic quantitative and structural parameters of mass flows of scientific and technical information).

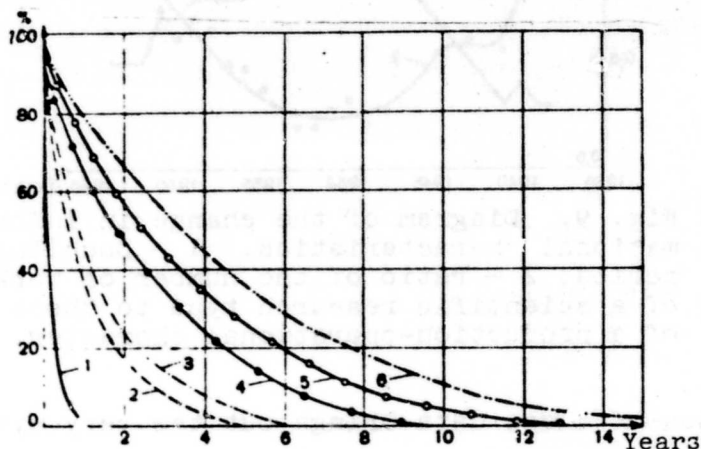


Fig. 10. Change in the value of information as a function of the type of source. 1 - Data bulletin; 2 - express information; 3 - journal article, production-technical; 4 - journal article, scientific-technical; 5 - monograph; 6 - description of invention.

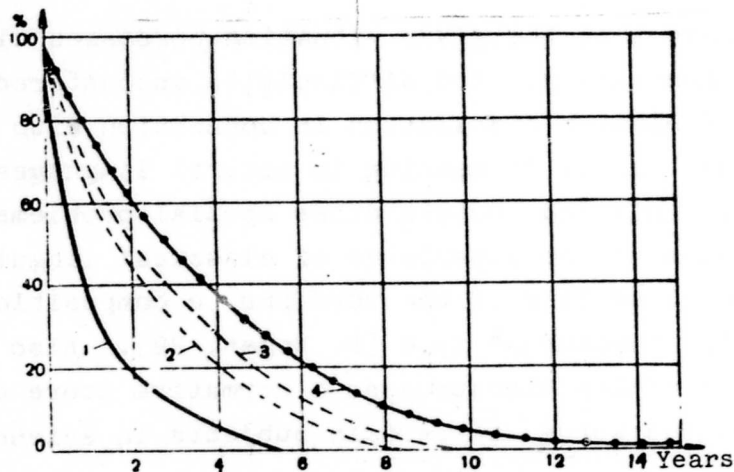


Fig. 11. Change in the value of information as a function of the sphere of its youth. 1 - Industrial; 2 - technical creativity; 3 - control; 4 - scientific research.

2. The treasure-house of ideas

The Marxist treatment of the dialectic connections between facts, the system of scientific ideas, and the new scientific facts anticipated by it is widely known and is confirmed daily by general practice. For us here it is important to emphasize that the process of scientific understanding (and of understanding in general) is inseparably connected with the functioning of the physiological and artificially man-made systems of accumulating information, and also to no small degree with the systematizing of information and ideas carried out by man or by technical equipment. The latter can be accomplished on different levels of abstraction, with a different degree of utilization of knowledge obtained earlier and of the logical potential at the disposal of humanity, but it is mandatory that it participate in the process of scientific learning.

In connection with the problem of forecasting, in particular if we can consider the future requirements and possibility of using for these goals various types of contemporary data-processing equipment, the problem of classifying the level of systematizing of information appears to us to be very urgent.

We will note that the given situation possesses significant gnosiological generality. The difficulties encountered by specialists in the field of machine translation in connection with the problem of the multidimensionality of meaning in natural languages are well known. For solution of this and certain other special problems it found to be necessary to turn to the experience of classical linguistics and to use a semantic classifier of the word-phrase composition of a language of the thesaurus* type [P. Roget, 29]. Also known is the broader concept of the thesaurus as a normative store of information (terms and related words) on certain subjects in science and technology [30].

In recent years interesting proposals have unfolded for using the thesaurus for purposes of quantitative evaluation of semantic information. W. Schrader proposed, for example [31], to use here as a criterion the measure of reconstruction of the thesaurus under the influence of information newly introduced into it (in accordance with principles accepted in the given thesaurus). The basic idea of this proposal is the objective fact that novelty of presentations about any object, expressed in the appropriate language of concepts, leads to a mandatory change in the structure of a given thesaurus.

In our view it is advisable and possible to develop a concept, broader than that now accepted, of the generalized thesaurus as a certain formalized system (aggregate) of information reflecting (with one or another degree of completeness) our ideas about objects of information and about the logical connections which are characteristic for them.

In accordance with data of historical experience and the logic of science, three essentially different types of thesaurus can be singled out: nominative (θ_n), functional (θ_f), and adequate (θ_a).

The thesaurus θ_n has the smallest capacity from the logical point of view. It actually contains only a listing of known objects

*Thesaurus (Greek) — a collection of valuables, a treasure-house.

(terms) connected by the single relator "to be a member of the class" of the given objects. A trivial example of such an accumulation of information is the inventory record, or, from the engineering point of view, the parts list of any device.

The most logically capacious thesaurus, Θ_a , is not only a reflection of the totality of objects of systematization known to us, but also - which is particularly important - represents the established scientific causal-consequence and other principal values of the connections between these objects. Classical examples include D. I. Mendeleev's periodic system of the chemical elements; the systemizing of the objects of living nature, constructed on the basis of the law of homologous series discovered by N. I. Vavilov; the systematics of elementary particles of Gel-Mann, and other similarly scientifically ordered aggregates of information.

In the majority of cases of scientific and technical practice we must deal with the functional thesaurus, occupying an intermediate position between the two types indicated above. During construction of a Θ_f it is no longer necessary to limit ourselves to fixing the known compositions of objects of a given class, but is still not possible to base its structure on the laws discovered by science for the development of the object. Proceeding from empirical information accumulated in the course of engineering and scientific practice, an effort is made during the construction of Θ_f to reflect the basic relationships between the systematized objects. The following relationships can be noted among them: similarity and differences in functions, proximity, relationship of the part to the whole, the hierarchy of functions and of cause-effect relationships (on the appropriate level of knowledge), etc.

Depending upon how closely the considered representations approximate scientifically known laws, Θ_f approaches Θ_a in its level.

A general summary of information about the three types of thesauruses is given in Table 3.

Table 3.

Characteristic	Type of thesaurus		
	Nominative, θ_n	Functional, θ_f	Adequate, θ_a
Definition	Fixing the composition of known variations of objects of a given class	In addition, reflects empirical presentations about relationships and connections of the systematized objects	Fixes the composition of known variations of objects of a given class and reflects the laws of the connections and relationships within the systematized aggregate as established by science
Examples of thesaurus	Catalog or parts list of a technical device	Engineering description of a structure	The periodic system of chemical elements
Rule of formulation	Objects are included without retention of logical connections between them	Objects are included with retention of those logical and functional relationships which are treated as basic on the existing level of presentations	Objects are included and the laws of connections between them established by science are fixed
Examples of problems which can be solved on the basis of the given thesaurus	General counting of known objects, information retrieval according to formal tags (for example, alphabetically or by order of appearance in θ_n)	Determination of new combinations of known elements, statistical analysis of the distribution "object - function," probability forecasting of expected changes in the structure of the given θ_f	Forecasting new elements with known properties and new properties of known objects. Forecasting new phenomena which may lead to changes in the given θ_a in the direction of increasing its adequacy

This classification of thesauruses is organically connected both with especially applied problems (e.g., the formulation of requirements for the logical capacity of a language or a system of codes as a function of the proposed form of their utilization) and with the general theory of forecasting.

D. I. Mendeleyev correctly asserted that "the scientific study of objects has two basic or final goals: foresight and use." In the end the question of whether it can be predicted can be answered only by proceeding from knowledge of the thesaurus with which a given effort at scientific and technological forecasting is undertaken.

It is important to emphasize that the position given strict mathematical proof in his time by K. Gödel (1931) relates to all three types of thesaurus. It can be expressed in the following form: in any and all systems to be formalized there will remain an unformalized residue.*

With application to the problem of forecasting, this important theoretical position, in this instance from the viewpoint of internal logic of the potential of science, emphasizes the principally probability nature of all forecasts. It also indicates the requirement for the most complete possible consideration of all possible connections and relationships of a phenomenon being subjected to forecasting with the conditions for its appearance and development, in order to increase the accuracy of prediction.

Scientific and technological progress can be treated from the informational point of view as a specific antientropic process. Actually as our knowledge grows the degree of uncertainty of information reaching us from the real world (in the general case -- through the scientific system) is diminished.

*In this regard see the discussion on the prospects of cybernetics in the book by M. Taube [32].

The position given above is seemingly in contradiction with the common intuitive experience. Louis de Broille writes with complete justification, "We must never forget (the history of science proves this) that each achievement of our knowledge brings up more problems than it solves, and that in this field each new discovery of open land permits us to assume the existence of immense continents yet unknown to us" [33].

For analysis of this situation, which causes the probability nature of scientific knowledge of such types as forecasting, we can propose the following interpretation. Let there be an infinite set M of facts* in the real world. Then the subset m of factors which have entered the scientific system can be presented in the form of a sphere with statistical radius r located within set M . The area of this sphere of scientific ideas, proportional to r^2 , will interpret the area of contact of the system of scientific knowledge with the remaining mass of possible facts in the real world.

An increase in the volume of scientific knowledge leading to an increase in the statistical radius of sphere m by Δr will simultaneously imply an increase in the field of contact of science with the elements of set M by a quantity proportional to $r + \Delta r^2$, along with a corresponding growth in the number of problems faced by science.

So far as there are bases for considering the increase in the volume of science to be proportional to time (the quantity of new results of science doubles every 40-50 years, and the quantity of scientific information doubles every 10-15 years), accepting the hypothesis of the predictability of the development of science is unavoidably connected with a significant increase in the future (hypothetical) area of contact of science with facts of the real world.

*In the broadest and most universal understanding of this term, close to concepts of "quanta of the formation process" [34] and "quanta of information" [35], and also with the condition of different methods of obtaining it [36].

Among these and especially important for the success of forecasting are interactions, varying according to different laws, of science with the area of material and spiritual life of the people (requirements and consequences, factors of progress and regression, etc.). A significant portion of these are as yet completely unknown; a certain part can be discussed only hypothetically, etc. But this very process of interaction of future science with the actual reality of the future will give confirmation or will refute the truth of the predicted knowledge and will specify the actual formulation of one or another scientific problem.

The outlined scheme of the mechanism which leads to a reduction in the probability of forecasts as they move forward into the future makes it possible to draw the following generalization: in the case of exploratory forecasts (the examined scheme is closest of all to this case) we can assume that the accuracy of forecasting future scientific and technological development diminishes inversely as the square of the MT lead time.

It is not without interest to note that after analyzing this question from the positions of the Shannon theory of information, V. Lisichkin and G. Zarubin arrived [37] at a result close to coincidence with the above.

It is appropriate to note in connection with the proposed interpretation that in the course of the actual history of science the influence of intensifying interaction of science with other spheres of life has led to a constant internal readjustment of the sphere of scientific knowledge. The circumstance that the volume of the indicated sphere is proportional to r^3 has a bearing on the evaluation of the dimensions of problems of this type.

The statistical theory of predictions under development today works out quantitative methods of probability forecasting and procedures for improving their accuracy. It is based on a hypothesis of the nature of prediction of the future very close to the problem under discussion. It "consists in this, that conclusions about the

possibility or probability of a future event or series of events are made on the basis of study, analysis, and generalization of past experience - the history of the phenomenon being predicted [38]. Of course, it is considered here that three components, differing in principle, always participate in real processes and are manifested to a different degree: a) a deterministic part, subject to exact calculation with any lead time sufficient for the purpose of the forecasts; b) a probability portion, revealed in the course of study (observation) of the phenomenon being predicted; here the statistical accuracy of prediction is determined in the main by success in establishing the probability of regularity of the development process; c) a random part, not subject to prediction from the positions of a contemporary level of knowledge.

The tactics applied in the statistical theory of prediction consist in the maximum possible isolation of the deterministic portion of the process and constant effort to refine (with growth in our knowledge) the prediction of the probability portion. A specific feature of forecasts of scientific and technological development consists in the fact that here we can accept the assumption of the deterministic nature of the process only in individual cases (and besides only in connection with forecasts of science as an organization). An example of this is the prediction of the Polish scientist K. Leski with respect to the growth in the volume of world scientific and technological information in the next 35 years.

Proceeding from the exponential growth of scientific information formulated over the last 300 years, Leski predicted [39] the following growth indices of the present huge volume of information: 1960 - 1 (taken as the base), 1965 - 1.4, 1975 - 3.5, 1985 - 8.0, 2000 - 23.0. This forecast, elaborated over the branches of scientific and technological process progress and type of information, is advanced as the basis for essential theoretical practical conclusions with respect to a number of aspects of future science.

We will note that in his calculation the author strove to introduce corrections into the historically formed rates of growth of information - corrections connected with the demographic development

of the major regions of the world, with the increase in the relative potential of developing countries, with a change in the percentage ratio of individual groups of people of the most creative age (30-40 years), with the change in the lower boundary of the age of beginning of creative activity, and also into the rate of growth of the number of personnel with higher education. Nevertheless the forecast proposed by him is very debatable, since it does not take into account the influence of the development of methods and means of scientific work, the maturing change in the form of scientific information carriers and channels for exchanging it, and a number of other factors according to which, as the author writes, "determination of the corresponding correction factors does not appear possible at the present time."

In scientific and technological forecasts we are dealing, as a rule, with dominating probabilities and purely random portions of the general process of development; this classes forecasts with such types of scientific knowledge as scientific hypotheses.

The indicated feature of the object of forecasting by no means removes the requirement for the use in this area of quantitative (including statistical) methods. On the contrary, the impossibility (at least in a given time) of analyzing a number of processes of scientific development with direct use of quantitative gages makes it urgent to seek out correlating connections of such processes and phenomena with processes and phenomena which are subject to quantitative analysis (for example, the growth in the number of scientific cadres, changes in the organizational structure of science, etc.).

The development in such an area of relatively more reliable predictions presents an increasingly imperative requirement that attention be turned to the experience and intuition of many natural scientists; their judgements about expected events also should be analyzed with the application of all statistical methods known for such cases. We can point out that contemporary mathematical theory of planning experiments is successfully developing its apparatus and expanding its sphere of application precisely by turning to the

experience of an appropriately selected circle of experts.

The development of models of the development of science with the use of the ideas of cybernetics, the study of science, information theory, probability theory, and mathematical logic may open very promising paths to a deeper understanding of the processes of scientific and technological development and to the production of forecasts which are more accurate in the probability sense. For example, work [40] presents an effort to use the ideas of the general theory of communications in forecasting.

In connection with the above, we consider it appropriate to note that in the mathematical structure itself, however perfected it may be, we are by no means inclined to expect the existence of general criteria of truth for scientific knowledge of the type represented by forecasts of scientific and technological development*. There are only two routes for general checking of the truthfulness of a prediction: the first is by comparing it with real future experiments**, and the second is by setting up an historical-logical experiment for the purpose of checking the present level of realization of some predictions made "in the past." In particular, such a check is of immediate concern with respect to informational methods of developing forecasts.

3. The study of science*** as the theoretical basis of scientific and technological forecasting

In the contemporary world every actually existing object is studied from different points of view and by different methods in a

*Certainly, specific problems of specific forecasts (for example, the certainty of the extrapolation interval, the degree to which the sample is representative, the logical consistency of positions, etc.) can and should be checked by existing mathematical methods.

**We will indicate that in this case an interesting problem arises for the logic of scientific research - establishment of the influence of the actual specifically made and authoritatively promulgated prediction on the path and results of its realization.

***Translator's note - literal translation of Russian word "naukovedeniye."

more or less broad family of science. But in fact science itself is an object occupying an increasingly significant place in human life, developing according to the laws existing in it. It is undoubtedly a most deserving object for scientific study.

Who accomplishes this study? Traditionally science was the object of study only for philosophers and historians of the natural sciences. Their approach to science was characterized by such features as:

a primary tendency toward cognitive and general theoretical goals, and not to the direct solution of specific practical problems ;

attention is concentrated on science as a system of knowledge and the question of science as an organizational system and as the object of control is virtually ignored;

the method of studying this object is predominantly descriptive, with generalizations being produced on the basis of historical and logical analysis of qualitative (and not quantitative) characteristics of the development of science.

In the first centuries of the existence of science such a position was valid, but it cannot be continued indefinitely.

Table 4 gives a summary of data which show the stages of scientific and technological progress with respect to the levels of complexity of known and created systems in connection with the increasing complexity of the nature of science*.

*Original ideas and some data by G. N. Povarov [41] were used in compiling the table.

Table 4.

Stage in the growth of complexity	Periods	Chronological limits	Quantitative characteristics (No. of systems or elements)	Qualitative characteristics of systems	Examples of typical systems	Characteristic features of science as a system of knowledge	Characteristic features of science as an organizational system
1	2	3	4	5	6	7	8
Stage of small (simple) objects	Initial	Early and middle paleolithic	10^0	Use of single objects	First signals	Accumulation of empirical experience and its transmission as heritage. First elements of education	-
	Mature	Late paleolithic					
	Initial	Mesolithic and early neolithic	10^2	Manufacture and use of single objects	Ancient symbol systems (beginning of writing)	First elements of education	-
	Mature	Late neolithic (after appearance of agriculture)					

1	2	3	4	5	6	7	8
Stage of large or complex (component) objects	Initial	Eneolithic age of the ancient East prior to separation of crafts and appearance of cities	10^1-10^2	Production of complex multicomponent objects and beginning of their systematic use	Multicomponent objects (large constructions, water mills). Sets of weapons	Formation of the first scientific systems	The individual scientist
	Mature	Urban civilization of antiquity and the Middle Ages			The system of urban economy		
	Beginning	Era of manufacturing production, XVI-XVIII centuries	10^2-10^3	As a rule, the systems have elements with determined interaction	Classical machines and systems of mechanisms (clocks, working machines, steam engines, electric drive). System of control by capitalist production		
Stage of small or simple systems	Mature	From first industrial revolution to end of XIX Century				Newtonian deterministic natural science. Preferential development of analysis methods	"Small Science"

1	2	3	4	5	6	7	8
Stage of large or complex systems	Initial	First half of XX Century (revolution in natural sciences)	10^0-10^6	Systems characterized by increasing complexity, that is, by massive stochastic [?] interaction of elements	ACS, automatic factories, systems for processing masses of information, Systems for controlling spaceships and complex experimental installations for scientific research. Systems for controlling the national economy	Creation of principles of relativity, statistical picture of the world. Systems (cybernetic) approach to study of objective world	"Big Science"
Stage of transforming or ultra-complex systems	Mature	Era of the second scientific and technological revolution					
	Initial	Boundaries XX-XXI Centuries	10^7-10^{10}	Thanks to the high level of organization, systems possess the capacity for growth, development, and conversion.	Devices for simulating complex cognitive processes, synthesized living material, global economic and data systems.	Science will have a clearly expressed metascientific character. Scientific heuristics, (methodology of creation).	Science is organizationally united with all systems of the activity of the social man ("Super-Big Science")

1	2	3	4	5	6	7	8
				Realization of principles of self-teaching and self-improvement [machines]	Systems for control of scientific, technological, and social progress	Knowledge of the united picture of the world (non-living and living material, humanity, society)	
	Mature	-	-	-	-	-	-

Contemporary science is a large, complex, dynamically developing system. A perceptible fraction of the national budget is devoted to maintaining it. Nations which are advanced in the scientific sense designate for science national wealth amounting to the production of two weeks out of the 55 [sic] in the year. The realization of the achievements of science ensures, in its turn, the principal portion of the growth of the social productivity of labor - from 1/2 to 3/4 of the growth in national income. Also exceptionally important is the theoretical and social effect of science, especially in a socialist society, creatively striving to build its life on scientific principles.

At the same time the losses caused by nonoptimum functioning of the organizational system of science are huge. In large modern scientific institutes a considerable portion of the budget of working time of scientists is frequently lost forever, and without justification. Owing to incomplete utilization of world-wide information, leading to duplication of investigations and development, in various areas of scientific and technological creations the specific weight of repeatedly proposed solutions reaches 60 and even 80 percent. In the largest developed countries the direct annual losses caused by this circumstance reach billions of dollars.

Modern science is faced by the problem, in all its magnitude, of selecting the directions of research and development with consideration of national interests and of the existing scientific potential. Labor and science was rapidly transformed into one of the most massive spheres of professional activity. In the last 50 years the number of scientists has doubled in the USSR every 6-7 years, every 10 years in the USA, and every 15 years in the nation of Western Europe. At the end of 1967 some 2.86 million people were working in the sphere of science and scientific services, of whom 770 thousand were scientific colleagues - comprising approximately one fourth of all the scientists of the world [42].

The principal significance for evaluation of such data is found in the following circumstances. The sizes of scientific collectives

grow by 2-3 times faster than the number of these collectives themselves. Here, as is known, the volume of problems of communication and control in collectives grows in proportion to the square of the number of their members. Added to this is the fact that the quantity of scientists of highest scientific qualification is increasing significantly more slowly than the total number of the basic cadre of scientific workers.

The experience of past years also showed that every forward step of science is achieved with increasing difficulty and with ever greater cost. In the last 40-50 years the doubling of the quantity of new scientific results has been accompanied in the world by 8-10-fold growth in the volume of scientific information, a 15-20-fold increase in the number of people in science, and a more than 30-fold growth in appropriations for science and for mastering its results.

Such a disproportionate growth in the quantitative characteristics of the organizational system of science cannot continue much longer. It requires the intervention of scientists in the very process of organizing research — self-knowledge of science. Science ever more imperatively senses the need for a transition from the tactics of "mass assault" on scientific problems to planned and coordinated cooperation of collectives of highly-qualified specialists, collectives which are well equipped technically, optimally organized, and scientifically controlled.

Such are the natural causes which activated research focused on specific and quantitatively determined scientific analysis of organizational and social aspects of the many years of experience of science. The object of these studies, thus, is the organization of the scientific process, of scientific activity as a form of professional labor. The goal is the formulation of theoretical principles of organization, planning, forecasting, and control of science. Consequently, we are speaking of the formulation by the efforts of scientists of many countries of the world of a new branch of scientific knowledge — "the science of science" [43], or, in accordance with the terminology which is accepted in the USSR and which, in our view is more apt — the study of science ["naukovedeniye"] [44, 45].

We shall give the following definition: *The study of science is a scientific discipline studying the experience of functioning of science in order to develop methods of increasing the effectiveness of scientific progress by utilizing means of organizational and social action.*

The study of science marches to its goal hand and hand with many other scientific disciplines. Long-standing connections with sociology, biology, and the history of science are being developed. Collaboration with cybernetics, information theory, operations research, and other scientific disciplines of the mathematical cycle is fruitful. Methods of evaluating the production of results of scientific labor and criteria for selecting variants of programs places the study of science together with contemporary divisions of economic science.

From this "structural material," on the basis of study of specific data about factors which are common and comparable in the vital activity of individual scientific disciplines the study of science develops its unique methods and concepts.

Departing from the descriptive, factological level of research, the modern study of science strives to find and analyze real principles and movements of forces of scientific and technological progress and, on this basis, to give a scientific explanation of the studied phenomena and processes. However, the explanation of phenomena is only one of the levels of scientific knowledge of the experience of scientific and technological progress. It by no means exhausts the problems of the study of science, which is primarily an instrument of action. It is appropriate to recall that even V. I. Lenin, stating the problem of specific study of the experience of the history of science, foresaw the regular sequence of the transition from qualitative methods of research to their dialectic unity with quantitative methods in the process of genuinely scientific research.*

*See: V. I. Lenin. Completed Collected Works, Vol. 29, pp. 298-301.

It can be asserted without exaggeration that the development of quantitative methods of analysis of the experience of functioning of science is today the most urgent and simultaneously one of the most complex problems of the study of science at the present stage of its development.

Some practical experience in this respect has already been accumulated both in the USSR and in other countries. This is indicated by a number of progressive trends: ever wider utilization of the methods of mathematical statistics, attention to the study of the system of structures and quantitative characteristics of flows of information on the experience of the functioning of the sciences, the use in research on science of ideas and methods of cybernetics, the application of machine methods for analyzing masses of historical and scientific information, including computer technology, etc.

The process of mathematization, which now encompasses a significant circle of sciences, has its own deep roots. This eases the growing requirements for science — requirements for positive results, mobility, conclusive efforts, and generality of the solutions which it proposes. The following can be considered to be the most important prerequisites for the mathematization of the sciences: on the one hand, a rising level of the mathematizing sciences themselves, their transition to knowledge of deeper laws of the investigated part of the objective world and a higher level of their logical apparatus and achievable generalizations; on the other hand, expansion of the boundaries of mathematics itself, the capability of its apparatus to develop, and the availability of contemporary powerful technical equipment for realizing mathematical methods and new areas of application [46].

In any case, in the absence of these components of the complexity of science it is difficult to count on real success in a system of analysis of past experience, diagnosis of contemporary conditions, and prediction of future science.

The question "What are the most important problems of the controlling organs of science?" cannot be answered in the form of

a list of the scientific and research problems underlying the solution. Such a list, however long it might be, would always be incomplete. Moreover, its formulation should be carried out not by the methods of chemical, biological, or any other sciences, but by the methods of the science of sciences. This is why we single out from the variety of research themes and specific problems faced by the student of science three central problems: effective use of existing capabilities and results of science, ensuring the growth of potential forces of science, and the development of a scientifically based strategy for scientific and technological development.

Experience shows that it is impossible to ignore any one of these most serious problems of the State control of science. A close connection exists between them: inefficient functioning of science is a manifestation of low efficiency in utilizing previously accumulated potential; with no assurance of the required scientific potential we must not count on future effectiveness of science, while errors in the basis of the strategy of development can bring to nothing the major portion of efforts in the field of scientific and technological progress. The student of science and the organizer of science must not behave like a sorry gardener who is concerned only with the collection of ripened fruits from the age-old tree of knowledge or who has no idea what sort of fruits he would like to grow.

Our idea on the complexity of the problems of the study of science is illustrated by Fig. 12. Here, in accordance with contemporary tradition, each arrow indicates the work which is to be transferred from one state (assignment) into another (result).

The set of specific scientific problems to be worked out by the theoretical and applied areas in the study of science naturally does not pretend to exhaustive completeness [47]. It is important to emphasize that upon achieving each of their specific goals, they must altogether ensure the development of the functionally most important, complex, and synthesizing central problems of the study of science. The point of intersection of two works designates the transfer of part of the results from one area to the other.

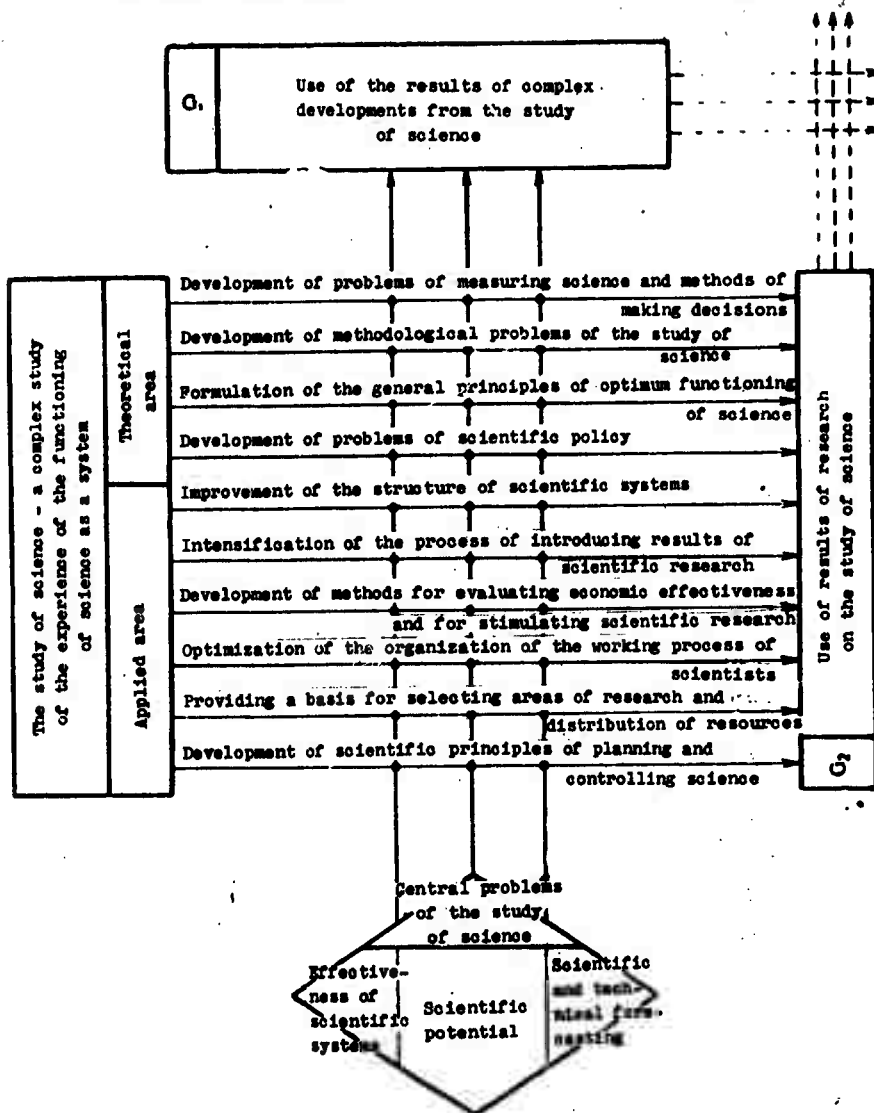


Fig. 12. System structure of the scientific problems of the study of science.

For specific reasons there can and must be noticeable changes in the actual set of works to be planned and carried out by one or another collective concerned with the study of science. Not all of the works will actually intersect in reality; this makes it possible to form clear judgements about the achieved level of complexity and

organization of research on the experience of the functioning of science.

However, with all these distinctions, the structure of the problems of the study of science must reflect its integrating function in the present world of science and a systematic approach to the study of objects.

In accordance with this type of orientation of the study of science there is a natural renovation of the shape of the presentation of results of research on science. The preparation of articles and monographs was formerly the single type of results of research on science; now these are ever more frequently supplemented with the development of specific recommendations directed toward more complete utilization of the accumulated experience and potential of science, improvement of its organization, and increasing the effectiveness of control. The purview of the study of science also includes the development of designs of new organizational forms of the development of science: experimentally verified organizational structures, types of communications, methods of stimulating scientific activity, forms of control of science, etc.

The final goal of the complex improvement of organization of the system of science consists in increasing the effectiveness of functioning of all its links, in creating more favorable conditions for the fulfillment by Soviet science of that historic role which has been assigned it in the common task of building Communism. The optimum utilization of the potential forces of science is one of the most important concerns of the Socialist state.

The unification of the problems of analysis, diagnosis, and forecasting during research on science is conveniently indicated on the example of the problem of scientific potential. The generally satisfactory concept "scientific potential" has more of the nature of a descriptive expression than of a scientific term. It is commonly identified with the concepts "intellectual potential," "creative potential," or "people of science." However, the difference between

availability of scientific personnel and their actual value under conditions of a different level of control of science is well known. "While agreeing that the number of scientists must in some way be increased," writes Professor N. Peary [?], "it is nevertheless useful to consider just for what we will actually use them.... There may be no deficiency of scientists should they set their own house in order" [43]. From this fact, known to every scientist, there follows the conclusion that it is necessary to consider the level of organization and the directivity of scientific progress among the parameters of scientific potential.

By limiting the circle of parameters of scientific potential to only the cadre, material and technical, and organization aspects, we risk falling into the same extremity as if during discussion of a needlework tablecloth, we concerned ourselves only the quality of the linen on which the decoration was inscribed.... Obviously, it is necessary also to take into account in a given scientific system the presence of a reserve of original scientific ideas, ensuring that it receives information about world-wide scientific experience, and the selected directions for application of scientific forces.

Proceeding from this, we consider it advisable to treat the category "scientific potential" as a complex of parameters characterizing the capability of a scientific system (institute, branch group of scientific establishments, science on the national scale, etc.) to solve present and future problems of scientific and technological development. On this scope the problem of scientific potential is in essence the problem of ensuring specific conditions and prerequisites for the satisfaction by science of public needs and for the realization of the accumulated capabilities of scientific development.

It is possible to clearly separate four basic groups of specific parameters of scientific potential (Table 5).

Depending upon the functional scientific system to which these characteristics belong, some or other components of scientific potential will have different significance. However, all of them are subject to quantitative evaluation and comparison.

Table 5.

Components of
scientific and
technological
potential

Parameters of the components of scientific
and technological potential

Provision of personnel	Total number	Qualified staff	The structure of scientific cadres by age	Availability of resources and reserves of scientific personnel
Provision of scientific infor- mation	Availability of a "reserve" of inherent scien- tific ideas and original proce- dures	Knowledge- ability of world exper- ience	-	-
Material and technical pro- vision	Financial pro- vision for science	Availability of scientific instrumenta- tion of appropriate class and an experimental base	Achieved technical level and the capabilities of industry	-
Optimality of the organiza- tion of the scientific system	Strategic principles of the develop- ment of science (criteria for selecting directions)	Optimality with respect to loss of scientific potential	-	-

Some years ago Professor J. Desmond Bernal, evaluating the course followed by the study of science over four centuries since it was first conceived, as outlined in his book "the Social Function of Science," wrote [48]: "the science of science, or the self-knowledge of science, is the most radical achievement of science of the second half of the Twentieth Century" [43]. For the sake of objectivity it should be noted that such a high evaluation of the study of science relates mainly to its scientific possibilities and to the exclusively important role prepared for it by the future history of science.

However, the assets of the study of science include results actually achieved. The most important of its applied achievements is the general acknowledgement of the progressive principle that the development of science can be planned; to a major degree this was facilitated by the experience in state organization and planning of the development of science in the Soviet Union, which was generalized by the world science of science. The new methods of planning, forecasting, and programming with research and development which have been created in recent years are of great practical significance. Based on the ideas of information science and equipped with contemporary mathematical apparatus, these methods are designed for application in complicated and complex scientific studies and are realized, as a rule, by means of electronic computers.

The following can be considered as the most important theoretical results of the study of science: the advancement of a united cybernetic (informational) concept of scientific progress, and also the formulation of a number of basic laws of the functioning of science. We will note two of these here.

1. *Law of accelerated motion of science.* In accordance with this law, whose first formulation was given by F. Engels, the general accelerated character of the development of science is a form of its vital activity. Science ceases to be science when deprived of this fundamental property, since this would indicate the termination of the growth of new knowledge — the death of science.

2. *The systematic nature of science.* In its nature science has a principally system character. Loss of this property would turn science into an accumulation of disconnected facts and would turn its creators into independent groupings or individually acting hobbyist-collectors. Thus, science as systematized knowledge resists not only ignorance, but also disorganized knowledge. What does science stand against as an organizational system? "System," wrote Safford Bier [?], "is one of the names of order, it is opposition to chaos" [49], and this system must be completely included in a science if it is actually a system.

There exists a certain set of criteria which distinguish each system from any other totality of elements. This is primarily an integral complex of mutually connected elements. A system possesses a certain structure which allows ramification of a hierarchy of elements. Interacting with the environment, it can be regarded as an element of higher order with respect to it, a broader system. Its structure itself is such that the elements included in it possess the properties of subsystems with respect to it. To anyone who is acquainted with the organization and functioning of contemporary science it is obvious that all the criteria and property of systems are clearly and completely manifested in it. In accordance with accepted classifications [49], it can be included in the group of very complex probabilistic systems.

The systematic nature of the organization of science is caused fundamentally by the principal and invariable systematic nature of scientific knowledge for whose generation, storage, and transmission it is designed. The level of systematic organization of both of these aspects of science is historical category. It was formulated and becomes more complex regularly in proportion to the scientific and technological progress of the human race (see Table 4).

There are a number of prerequisites for broad utilization of the mathematical theory of systems and of operations research methods in analysis of experience through the study of science. Operations research method will, apparently, play a significant role

in applied research related to the study of science. Appearing as the "art of giving poor answers to those practical problems for which other methods give even poorer answers" [50], the study of operations has developed in recent years into a highly perfected mathematical apparatus for making decisions.

These methods might be used during the development of the following applied problems of the study of science, all important for the analysis, diagnosis, and forecasting of science:

study of the complex of problems of requirements and distribution of resources (financial, material, human);

analysis of the optimality of organization of research operations and scientific establishments;

development of methods of selecting the areas of application of forces;

planning, forecasting, and controlling complex research programs.

However, the realization of these possibilities depends in the main on the correct answer to the question: "what can be measured in science?" For we consider an important stage in the formulation of the study of science as a branch of scientific knowledge to be the creation of tools for analyzing scientific experience -- systems of gages of processes and phenomena of scientific development.

Science as the sum and system of knowledge is an object falling within the sphere of human intellectual activity. At the same time, scientific knowledge appears, is developed, and is used for practical purposes in specific material forms and conditions. A significant portion of the latter are commensurate or, in any case, are subject to definite calculation.

These real materialistic prerequisites served as an impetus to concentrated study of long-standing statistical data: on the quantity of scientific results (including discoveries and inventions), printed works, and in general the intensity and structure of the flow of scientific information, the number of people engaged in science,

the quantity and structure of scientific establishments, the magnitudes of capital outlays in science and the economic effectiveness of scientific developments, the frequency of subsequent use of research carried out at some time. One can also take into account the growth of the expanding capabilities of telescopes and their quantity, the capacity of synchrotrons, the number of scientific journals, etc.

One of the essential factors hampering objective analysis and comparison of data about the experience of functioning of scientific systems is the random compilation and unordered (in any country in the world) formulation of official statistics of science. The effort to introduce a single approach to the definition and measurement of the objects of science considered by official statistics, undertaken in recent years by UNESCO and other international organizations, cannot as yet be considered successful.

The dynamics of the changes in time and across branches of knowledge of a similar type of indices ordinarily characterizes one or several essential features of the development of science. Their totality makes it possible (although indirectly, but in a number of cases fairly objectively) to judge the rates and trends of the development of science. More possibilities are opened by comparison of information of this type of science with data on the development rates of certain branches of science and production.

The appearance in recent years of developed concepts and complex methods of scientific and technological forecasting can be regarded as an important stage, in both theoretical and applied respects, of the formulation of the science of science. These introduce a new essential element into the system of knowledge formulated by the study of science.

The purview of the study of science and, in particular, of forecasting ever more frequently includes not individual problems of the development of science or of a new technology, but of the development of the scientific and technological process of a whole,

beginning in the area of exploratory research and ending in the sphere of practical innovations.

During the development of promising plans for the development of science and technology and a long-range forecast of scientific and technological progress, Soviet scientists proceed from the principle of an ever-growing role of science. During the formulation of forecasts the scientists utilize the richest scientific and technical experience accumulated by generations; they base their work on the laws of development of science and technology, striving for deeper penetration into the logic of the development of definite principles, scientific ideas, and technical equipment.

As an illustration of the number of important laws, trends, and principles of the development of technical equipment we can cite the following.

Succession in the development of technology, which is sometimes called also the "law of the spiral." Its essence consists in the fact that technology is developed on the basis of accumulated experience and in its forward development it frequently returns to "old" technical ideas, utilizing them on a new scientific and technological base. One of the numerous examples of this is the return of modern metallurgy to the converter method of smelting steel, utilizing an oxygen blast. Specific principles ensuing from regular succession in the development of technical equipment include the principle of historical relativity of the evaluation of technical ideas and the profound conviction of innovators that "a better solution can always be found."

Trend toward more complete utilization of the capabilities included in a specific scientific and technological idea. It is manifested in the expansion of the sphere of application of technical equipment created to solve a certain production problem; in delimiting the areas of application of old, traditional equipment as new equipment appears; and, finally, in the constant improvement of existing technical equipment. However, as this process develops the

basic indices which characterize the effectiveness of a given type of technology gradually approach a certain level. This usually indicates the onset of a limit of the possibilities of the technical idea and points to a need for qualitatively new decisions in this region. As an example we can cite the many years of efforts of scientists and designers directed toward finding methods for increasing the efficiency of the steam engine, terminating finally in transition to use of more effective thermal and electrical machines.

The regularity of the entire intensifying influence of science on the development of technology and production. Where in the past centuries the development of science was determined, to a great degree, by technology, at present the achievements of science determine to an ever greater degree the development of technology itself. This is explained by the unprecedented rate of growth of the level of science itself and by the fact that contemporary technology shifts to utilization of ever deeper laws and properties of matter, taking upon itself the problem of using not only the physical, but also the mental labor of humanity. Contemporary technology is characterized by the active interplay of sciences which for a long time were considered to be remote from one another — e.g., psychology, mathematics, and cybernetics.

Also very characteristic for the development of technical equipment is the *trend toward excluding intermediate links*. Examples in the area of technology include the following: flow lines, the use of electrospark for metalworking, direct reduction of iron from ore, etc.; in the power-engineering field examples include direct conversion of thermal into electrical energy; in construction we can cite the combination of operations into combined machines, designing of new lifting surfaces of aircraft with functions of a propelling agent, etc.

One of the most important laws of the development of contemporary technical equipment is the *transition from a system of complex mechanization of production processes to automation of production*. In the area of machine design this is expressed in a massive

transition from the traditional three-link system (motor, transmission, working machine) to systems with feedback, equipped with automatically acting monitoring and control devices.

The development of technology is also facilitated by the *mutual enrichment of its various branches with experience and ideas*. Examples of this are the use of the idea of the wing in shipbuilding, the broad possibilities of using the electrohydraulic effect, etc. A particular manifestation of this law is the principle of "reverse" action. (The waterwheel, for example, served as the prototype of the paddlewheel for the first steamships, the wind motor gave the idea of the screw, etc.). A characteristic feature is the fact that radical changes in any one branch of technology inevitably lead to essential changes in other branches. A clear example of this is the influence on technology of the achievements in production of artificial and synthetic materials.

An old trend in the development of technology is the *use of experience of living nature*. The first locomotives had attachments which imitated the action of the legs of horses. Contemporary cybernetics investigates the mechanism of the working of the human brain, attempting to make creative (and not strictly imitative, as in the previous example) use of certain principles of the activity of living material.

It should be emphasized that an essential factor for understanding the process of the development of technology is the applicability of the effect of one of the most general laws of nature - the so-called *law of reverse sanctioning* of (efferent) communications [51]. In the area of living nature this law is manifested, for example, in the mechanism of natural selection. In the field of technology, sanctioning branches of feedback are closed through the human, who creates, uses, and evaluates technology in accordance with his particular features, world view, and social and economic position.

The science of science is a young branch of scientific knowledge. Solution of its many cardinal scientific procedural problems is still

in the future. Special attention is paid to increasing the theoretical level of research on the study of science. Only on the basis of developed theory, checked by the living experience of practice, will it be possible to formulate, refine, and specify a system of general fundamental scientific laws of the functioning of scientific and technological progress and thus to raise the study of science to the level of an effective theoretical basis of contemporary scientific and technological forecasting.

CHAPTER III

FORECASTING IN CONDITIONS OF THE CONTEMPORARY SCIENTIFIC AND TECHNOLOGICAL REVOLUTION

1. The law of accelerated development in action

The road of human development is colossal in scale and in the depth of transformations. On all stages of the progress of human society the development of means of labor, engineering, and technology, the use of the achievements of science in social practice, have played an outstanding revolutionizing role. At the same time, the social and economic conditions themselves have influenced to a decisive degree the tempo and nature of scientific and technological progress. Perceiving this dialectical connection, Karl Marx wrote in "Capital": "Economic eras are distinguished not by what is produced, but by how it is produced — by the means of labor. The means of labor are a measure not only of the development of human labor and capacity, but an index of those social relationships under which work is accomplished"*..

The rates of scientific and technological progress have been noticeably accelerated in the last three centuries. We should note a circumstance important for understanding the original cause of this process: the accelerated tempo of scientific and technological development was forced by the accelerated growth in the population of the Earth — by the exponential growth in the requirements of humanity.

*K. Marx and F. Engels. Writings, Vol. 23, p. 191.

In its turn, scientific and technological progress itself has rendered a positive influence on the growth and expansion of the variety of requirements of social man.

The most important feature of that "internal mechanism" of scientific and technological progress which made it possible to guarantee accelerated rates of development is the intensification of connections and comprehension of interactions between science and technology, between scientific and technological progress and social production. Formulation of this mechanism began in the years of early history, but only the eras of the first industrial revolution (XVIII Century) and the present scientific and technological revolution introduced qualitative and quantitative innovation into the process of interaction of science, technology, and production, raising science to the level of a direct productive force and bringing production to the level of the sphere of materialization of the "products" of scientific knowledge.

The scientific and technological revolution of the second half of the XX Century is based first of all [1] on the vast achievements of such natural sciences as mathematics and physics. Mathematics, with its most universal methods and generalizations, found broad application not only in the technical sciences and physics but also in biology and the social sciences. In particular, mathematics made it possible to study the structure of the nucleus of the atom, thus facilitating (as it continues to do) the development of nuclear physics. Such branches of physics as electrical engineering and electronics comprised the basis for development of more effective means of controlling production processes, scientific research, transport devices, etc. Penetration into the secrets of the structure of matter - splitting of the atomic nucleus - lead to the production of a type of energy new in principle - atomic energy, not existing in nature in "finished" form. Physical methods of research - x-ray, the electron microscope, the use of tagged atoms, and the methods of molecular physics - permitted deep study of the structure of matter and its mechanical, electrical, and thermal properties; thus they gave a perceptible stimulus to the development of the chemistry of organic

synthesis. The methods of organic synthesis make it possible to obtain an innumerable quantity of synthetic materials distinguished by valuable properties: high strength, long service life, low density, resistance to the action of aggressive media, etc.

The development of cybernetics and rocket technology also comprises an important feature of the new scientific and technological revolution of the second half of the XX-th Century. Cybernetics has become the basis for automation not only of physical labor but also of mental work. The achievements of rocket technology have lead to the penetration of man into outer space.

Thus, the essence of the contemporary scientific and technological revolution, generally speaking, consists in the following:

- rapid general growth of technology and the availability of power for labor;

- specially accelerated development and ever broader practical application of automatically operating means for replacing the physical and mental labor of man;

- mastery of new sources of energy and practical utilization of the achievements of nuclear physics;

- broad use of the achievements of chemistry, in particular new materials created by man himself;

- successful development of means of transport and communications which bring closer the most distant points of our planet and open the road to space to mankind;

- exceptionally vigorous development of science (especially its "frontier" fields); a high level of practical results of scientific research, raising science to the level of a directly productive force.

The scientific and technological revolution of the second half of the XX Century is simultaneously characterized by the following: accelerated rates of scientific and technological progress, interweaving of scientific and technological problems, a growing role of science in the solution of production problems, an increase in the

level of scientific leadership of the economy, and in the socialist countries - all of the social and economic processes of social development [53, 54].

Historically conditioned and regular acceleration of rates of scientific and technological development is manifested in specific forms which are essentially different but which are always important in principle. In this connection it is important to turn attention to the following five groups of characteristics (from the point of view of the study of science) of the contemporary stage of scientific and technological progress.

1. As science develops, such scientific events of principal importance as refinement and renovation of fundamental views and research methods and establishment of scientifically new capabilities for utilizing laws of nature which have been learned occur at an accelerated pace. Here is a characteristic chain of examples: the Aristotelian theory of gravitation existed for over 2000 years; Newton's concept waited 200 years for its generalization and essential refinement; the atomic-corpuscular theory of Dalton and Avogadro, based on the concept of the indivisibility of the atom, determined the views of the structure of matter for a century; the Rutherford and Bor theory of atomic structure has existed now for about 10 years.

Figure 13 shows data which indicate how the renovation of research methods ensured a growth in the rates of discoveries of new chemical elements. Figure 14 shows how the renovation of the principles of acceleration of elementary particles ensured accelerated growth of accelerator energies, and thus increased the cognitive possibilities of scientific processes based on their use.

2. The rates of innovation of applied scientific and technological ideas and of the growth of the final resulting parameters of the new technology are increased; the time required for industrial realization of scientific ideas is shortened to the passage "from flask to cistern."

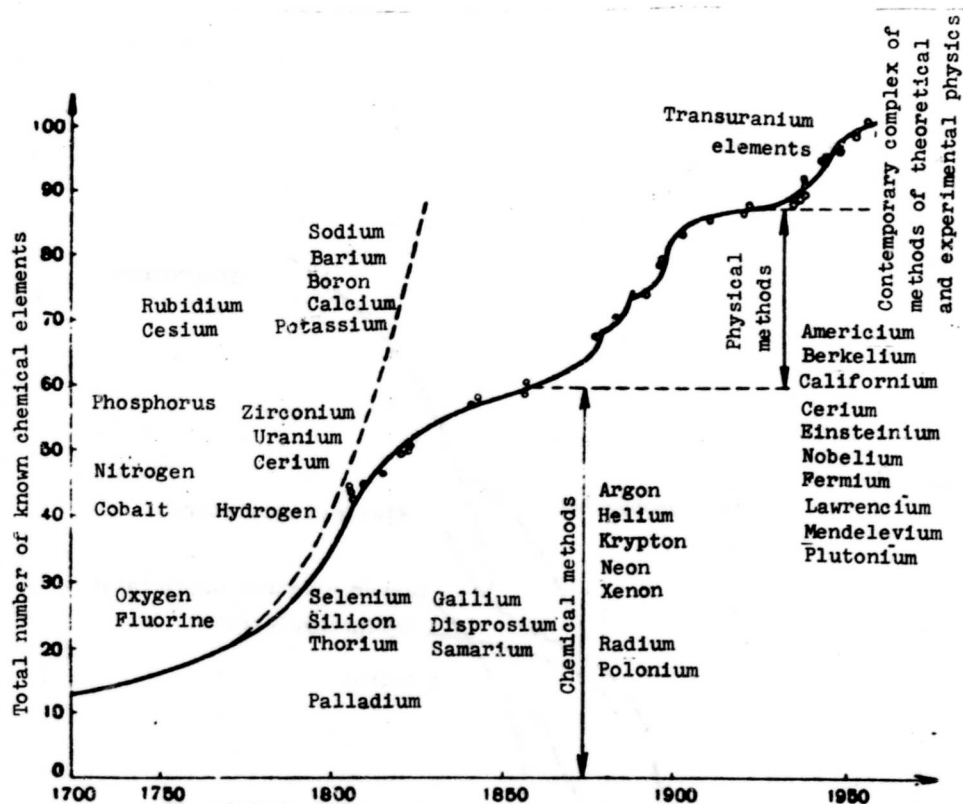


Fig. 13. Diagram of the dynamics of discovery of new chemical elements.

The dynamics of the growth of speeds of transport equipment caused by the introduction of new operating principles is shown on the diagram in Fig. 15.

The trend toward shortening of lag - the time required to convert from laboratory research to mass production of various types of polymers - is evident from the data in Table 6*.

Figure 16 presents data on the change in lag times over a broad circle of the objects of scientific and technological progress.

*Compiled by G. A. Samoylov.

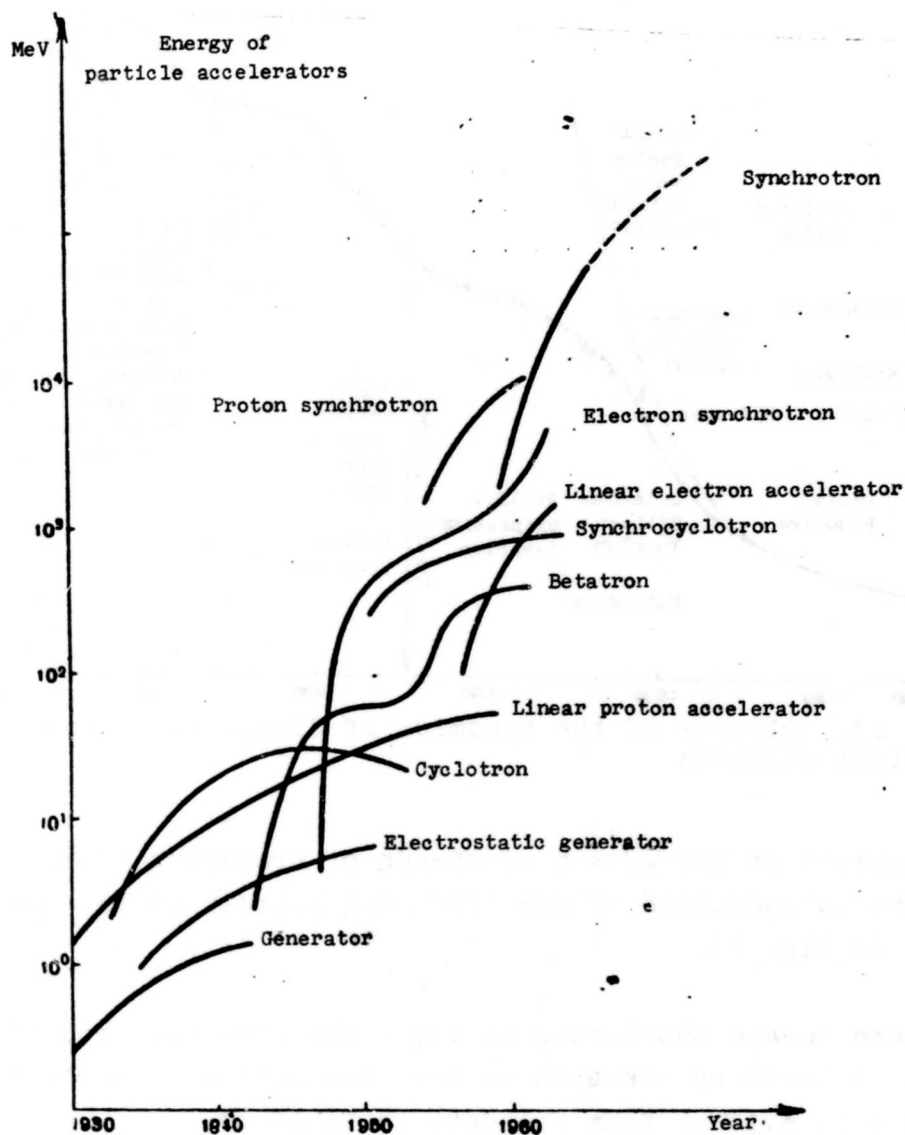


Fig. 14. Rates of growth in the power of elementary particle accelerators.

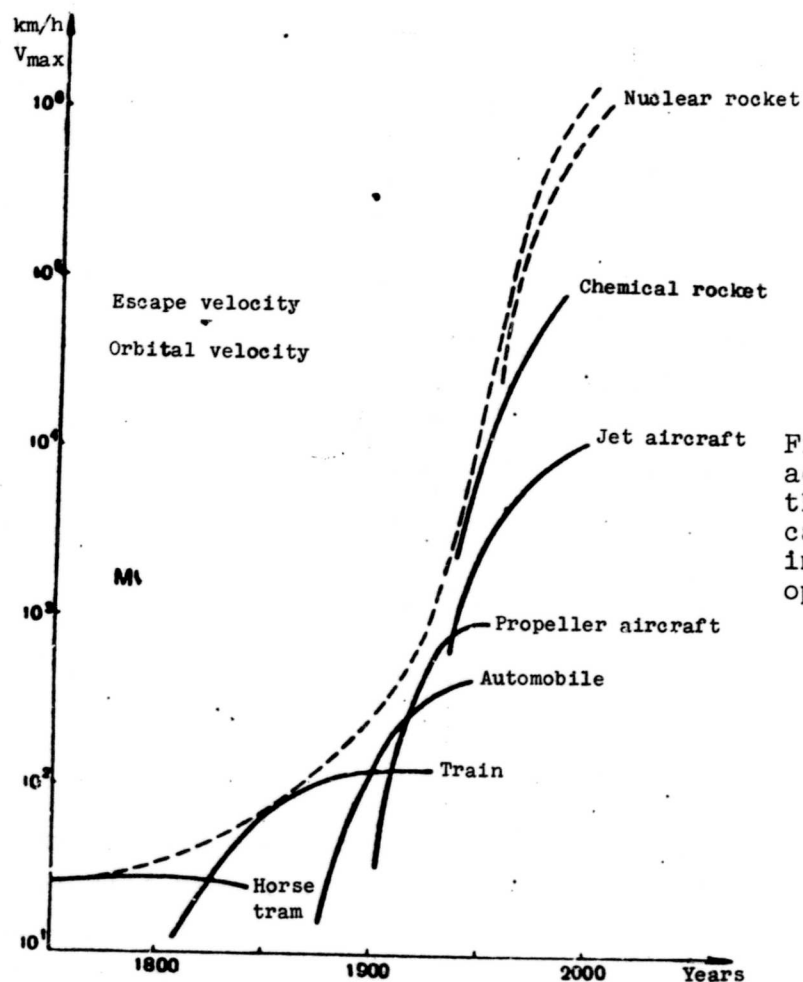


Fig. 15. Trends of accelerated growth in the speed of transport caused by innovations in the principles of operation.

Table 6.

Polymer	Year developed	Year production begun	Duration of lag, years
Polystyrene.....	1839	1930	91
Polyformaldehyde.....	1859	1938	99
Polyvinyl chloride.....	1872	1935	63
Phenolformaldehyde polymer.....	1872	1909	37
Polyisoprene.....	1879	1956	77
Ureaformaldehyde polymer.....	1884	1925	41
Polyacrylonitrile.....	1893	1943	50
Polycaprone amide (caprone).....	1899	1939	40
Polibutadiene.....	1911	1931	20
Polyundecane amide (Ril'san).....	1935	1950	15
Polyhexamethylene adipinamine (nylon).....	1935	1938	3

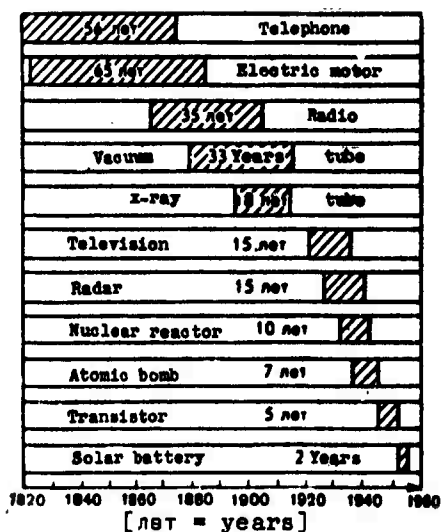


Fig. 16. Change in lag times in the course of scientific and technological progress.

The facts presented should not be interpreted as evidence that progress of science and technology is becoming an ever simpler and easier affair. It is precisely the opposite — every step forward in scientific and technological progress is connected with penetration into ever deeper laws; it requires the application of ever greater efforts and is achieved at ever greater cost.

This, on the one hand, strengthens the value of the trends expressed by the discussed data, and on the other hand it gives rise to a group of new characteristics (from the point of view of the study of science) of scientific and technological progress.

3. The "mass" and "inertia" of organizational forms and specific conditions of scientific and technological development have grown: the depth of professional specialization is intensified, the term of training scientific people is elongated, the fraction of long-term scientific programs and the total volume of research and development grows, and the complexity and capital investment of experimental works are increased; in addition the information situation in science is enormously complicated and the equipment of the scientific process with powerful but narrowly specialized instrumentation grows, etc.

The rapidly increasing urgency of this problem can be illustrated at least by that fact from the study of science that in the past decades of the Twentieth Century each doubling of new results in science and technology (discoveries, inventions, new research data, newly obtained materials, etc.) was accompanied by approximately four doublings of the volume of scientific and technological information, and on the order of five doublings of the number of people working in science and more than six doublings of the means being applied in science. Although the direct and immediate benefits obtained through the ever broader application of the final results of scientific and technical progress overlapped by many times and in growing proportion expenditures of this type, spontaneous development of this process becomes impossible.

4. The system nature of scientific and technological progress is intensified and complicated. Now in an ever greater number of cases the idea of speaking only about the progress of technology or of an individual branch of science becomes meaningless. As a rule we are dealing with a unified phenomenon — scientific and technological progress, in which the initiating role is played by deep scientific research. At present vitally important connections of science and technology with the broader economic and sociopolitical systems are especially clear and sharply felt. The perceptive words of Vladimir Il'ich Lenin, taken as the epigraph of this book, "The economist must always look ahead, in the direction of the progress of technology; otherwise he is quickly left behind*...." are true in our era as never before.

5. The synthesizing and generalizing characteristics of contemporary scientific and technological forecasting lie in the fact that in our day science is being converted into a directly productive force of society over an ever broader front and in an ever more active form. This adds a feature which has no analog in the distant past, and it imposes responsibility on those who are called upon to accomplish planning and control of scientific and technological development.

*V. I. Lenin. Complete Collected Works, Vol. 5, pp. 137-138.

The simultaneous action of the cited factors itself defines the difficulty of controlling the complex inertial mechanism of scientific and technological progress. The changes in concepts of scientific and technical development which occurred in the past centuries once in 100 years or once in 30 years can now catch us unaware five times more often – every 20 years, or even every 6-10 years – if decisions made on the paths of development of science, technology, and production are not made on a scientifically based level of foresight.

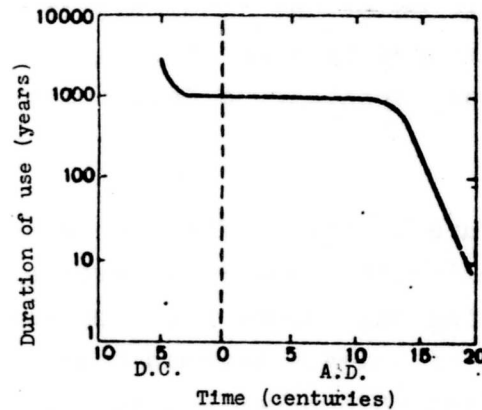


Fig. 17. Historical trends in changes in the "lifetimes" of technical equipment of armaments.

It is appropriate here to bring in two examples which argue the position stated above. One of these (Fig. 17) shows [55] the historically accumulating changes in the "lifetimes" of technical means in armaments; the other (Fig. 18) presents a summary of data on the renewal time of the technical characteristics of different types of industrial production emerging on the world marketplace.

According to the common evaluation made in the study of science, the requirement of socially necessary time for the passage of a scientific idea from the stage of fundamental and exploratory research through the stages of applied research and experimental design work to production and commercial realization of new types of production comprises 10-15 years; of these 6-8 years are expended on the path from applied research to lot production. According to this the contemporary rate of renewal of scientific instrumentation of research

laboratories is evaluated as 4-5 years, and frequently even less [56].

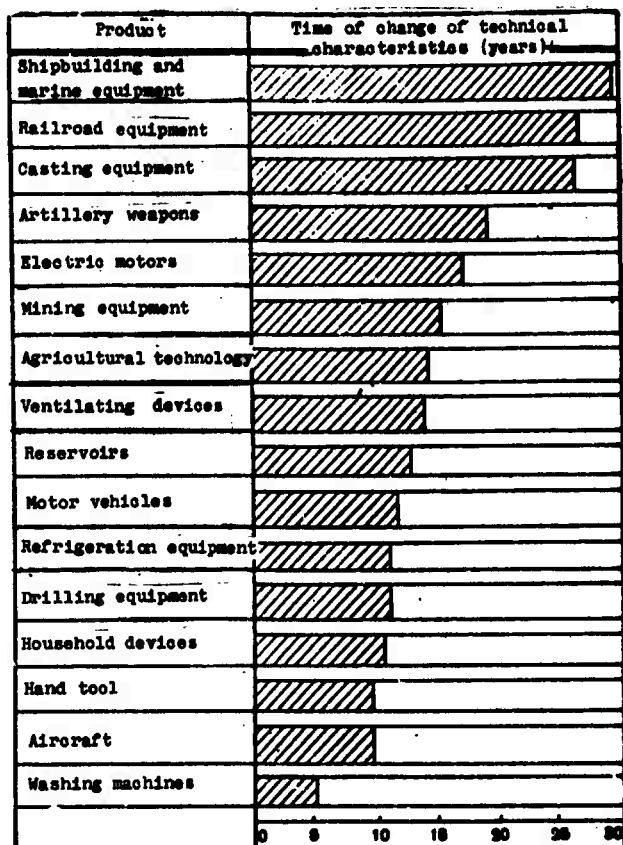


Fig. 18. Time required for a change in the technical characteristics of various types of industrial production.

The time factor, always playing a significant role in the social and economic life of society, in the present day takes on a special (and without an analog in the past) significance as a unique economically conditioned regulator of specific processes of scientific and technological development. The principle of "better late than never," in force for centuries with respect to scientific and technological creativity, is now ever more frequently and imperatively being replaced by the principle "either on time - or don't do it," because scientific results which are either not obtained or not

realized in time with an interval on the order of the decade can usually be obtained from scientific and technological information or, more advisedly, can be picked up in the form of a license. Students of science, formulating the criteria of selection and evaluation of directions of scientific research, can no longer be satisfied with the traditional criteria of simplicity, refinement, or the paradoxical nature of scientific theories. They are more inclined to reject the thought expressed some two centuries ago by the Dutch thinker Hamster His: "That is excellent, which gives the greatest number of ideas in the shortest space of time."

In view of the action of the law of accelerated development of science, contemporary society has for the first time been given the possibility, based on the achievements of science and technology, of achieving essential increases in the productivity of labor and effectiveness of social production in a very brief historical period, ensuring that production corresponds to the world scientific and technological level, and making production competitive in the world marketplace. Organized and suitable innovations have become the key point in economics and policy.

2. Economic urgency of scientific and technological forecasting

The progress of science and technology, playing since ancient times an important role in the development of the economy, is characterized in the era of the contemporary scientific and technological revolution not only by vigorously growing rates and other quantitative parameters. There has occurred an orderly transition of quantity to a new quality — the action of the factor of scientific and technological progress has become predominant and determining for many aspects of the economics of production. "...Science and technology," in the sagacious words of K. Marx, "give working capital the ability to expand, independently of its given quantity."*

*K. Marx and F. Engels. Writings, Vol. 23, p. 619.

Table 7.

Country	Annual increment, %			Evaluation of participation in the increase in the gross national product, %			Value of the fraction of the scientific and technical progress factor in the growth in GNP, %
	Labor force	Fixed capital	Gross national product	Labor	Capital	Scientific and technological progress	
FRG.....	1.6	6.0	7.4	1.1	1.8	4.5	60.8
Italy.....	1.1	3.2	5.9	0.8	1.0	4.1	70.0
Holland.....	1.2	4.8	4.8	0.8	1.4	2.6	54.2
France.....	0.1	3.4	4.5	0.1	1.0	3.4	75.5
Norway.....	0.3	4.6	3.4	0.2	1.4	1.8	52.9
Sweden.....	0.5	2.0	3.4	0.3	0.6	2.5	73.6
Belgium.....	0.3	2.6	3.0	0.2	0.8	2.0	66.7
England.....	0.6	3.1	2.4	0.4	0.9	1.1	46.0

Science, having received the call to become the "means for the production of riches," has become the object of attention of economic science over an ever broader spectrum of its process. From the study of "the out-of-plant stage of preparation of production," in which basic attention is turned to the stage of experimental design work and mastery of new technology, economic analysis tends to expand as a whole to the area of "scientific production" - the creation of the science of potential consumer costs [57, 58, 59].

The growing economic urgency of the factor of scientific and technical progress is conditioned both by the high rates of change of the means of labor and production of industry (these are evaluated on the average as 10-15% per year, with rates of 30% in the "new" branches and about 7% in the "old"), and also by the dominating fraction of direct participation of scientific and technical progress in the increase in the gross national product. Comparative data on the fraction of participation of technical progress, the increment in the labor force, and the fraction of fixed capital for the group of economically developed European capitalist countries in the 1950's are given in Table 7.*

The given data clearly indicate that in all countries which achieved high rates of development of production in the 1950's the scientific and technological progress factor played a determining role in the process. The experience of the development of the majority of Socialist countries testifies very persuasively to the

*Compiled mainly from data in work [60]. Cited in work [61], which presents a well-based criticism of the methodology of converting such data; however, the evaluation of the role of the factor of technological progress, of interest to us, is not changed. The term "gross national product" (GNP) indicates that earnings from the export of capital have been excluded from the national product.

Data on the FRG are for the period 1950-1955 and data for the remaining countries cover 1949-1959.

We calculated the fraction of the scientific and technological progress factor in the increment in the GNP as a ratio (in percent) of the valuation of the factor of scientific and technological progress to the annual increment in the GNP.

same thing. According to the evaluations of Soviet experts, every ruble invested in research and development has ensured a growth in the national income of 1.45 rubles in the USSR; this is approximately four times higher than the corresponding index of the total effectiveness of planned expansion of industrial funds [V. A. Trapeznikov - 62]*. T. S. Khachaturov evaluated the effectiveness of capital investment in scientific and technological education as four times higher than the total effectiveness of financing of the national economy [63]. It is expected that as the result of the use of achievements of science and technology in the national economy of the USSR in 1960-1970, savings in labor will be achieved on no less scale than that of the labor occupied in production in 1960 [64].

In contemporary conditions economic success of production is achieved not only by the rate and scales of deployment of production itself, but in an ever greater degree by the rates and scales of mastery of more progressive forms of production, a high scientific and technological level of productive forces, by the presence of an advance reserve in levels of industrially mastered technology, design and development work, and prospects for subsequent use of scientific research [65].

In contemporary world production, these scientific research works ever more frequently are called the "moving forces of world leadership" [66]. In any case it is quite well known that underestimating research and bases for selecting promising scientific and technical policies is the principal reason that in the last 50 years in the United States alone some 66 out of the 100 largest corporations

*S. Golosovskiy, in calculating this evaluation (Determination of the Economic Effect of Scientific Research and New Technology, "Problems in Economics," 1968, No. 6, pp. 75-85) by a procedure which takes into account preceding expenditures and their dynamics, derived somewhat smaller figures; however, these are also 3-4 times greater than data on the average effectiveness of capital investment in the national economy as related to the compared periods.

have vanished from the scene [59]. The fact that the English have lost their position in the world and European marketplaces is connected with the same reason [67].

We shall introduce several instructive examples*. At the end of the war English specialists, predicting prospective designs of automobiles, give a negative evaluation of the idea of creating a small automobile with the motor located in the rear. In particular, this was the basis for the English refusal to accept as reparations the initial documentation of the German design of the "Volkswagen." After 12-15 years this technical decision was the reason for the severe losses suffered by a number of English and also American firms on the world market.

Enormous losses followed the error by experts of the firm "IBM," who underrated the prospects for lot production of the IBM "ENIAC" and the use of disk memories in electronic computers. While the firm managed after 10 years to correct these errors (although they caused large losses), nonetheless because of failure to properly evaluate the prospects for creating an operationally effective multiple copying device the firm "IBM" lost part of its market. It was taken over by the production of the firm "Xerox," which although less powerful in the financial respect did make the proper decisions in good time.

The postwar prediction of the promise in scientific and technological progress in the production of synthetic fibers was justified up to a level of 90%; this made it possible for a number of firms to concentrate research efforts in a timely manner and to achieve great economic success [69]. Investigators of the international experience in scientific and technological forecasting have correctly noted the outlined tendency to an increase in accuracy of forecasts - a growth in the number of validated predictions [69].

*An extensive collection of successful and unsuccessful forecasts can be found in the work by I. D. Ivanov [67]. The data on the forecasts examined here were taken from it.

Table 8.

Nature of predicted achievements	1950-1952	1953-1954	1955-1956	1957-1958
1	2	3	4	5
Theoretical research	Discovery of hydrogen radio emission in space (1951). Synthesis of cortisone (1951). <i>Deciphering of the excitation mechanism in the brain (1952)</i>	*Synthesis of oxytoxin (1953). *Decoding of the structure of the insulin (1954). *Formulation of the proposed structure of DNK (1953). <i>Deciphering of the inhibition mechanism in the brain (1954)</i>	Antiproton (1955). Antineutron (1956). Confirmation of the existence of the neutrino (1956). *Synthesis of reserpine (1956)	<i>Refutation of the "parity principle" (1957). Discovery of radiation belts of the Earth (1958). Element No. 104 (1958)</i>
Inventions and achievements of experimental production	Semiconductors (1951). Nuclear power reactor (1951). *Thermoelectric explosion (1952). "Artificial heart" equipment (1952)	Betatron (1954). Solar battery (1954). Nuclear reactor of the "water-boiler" type (1953). Supersonic flight (1953). Maser (1954)	Vertical takeoff aircraft (1955). <i>Cryotron (1956)</i> . Contraceptives - tablets for oral use (1956). Artificial creation of rain (1955)	Thermionic converter (1957). Intercontinental missile (1956-1957). *Artificial satellite (1957). *Laboratory creation of a DNA-like molecule (1958)
Mastery of production and sale in the marketplace	Orlon (1950). <i>Antibiotics, accelerating the growth of plants and animals (1950)</i> . Beginning of automation in the auto industry (1951). Huge computers for government needs (1951). Zone melting (1952). Telerelay lines (1951).	Dacron (1953). Wide-screen cinema (1953). Silicon transistor (1954). Color television (1953). Chemical "machining" of metals (1953). <i>Accelerators (1954)</i> . Large computers for industry (1954).	*Salk vaccine (1955). Turbo-prop aircraft (1956). Polyurethane resins (1955). Computers for weather forecasting (1955). Video magnetic tape recorder (1956). *Atomic submarine (1955). Industrial atomic power (1956)	*Vertical takeoff equipment of the "jeep" type (1958). Linear polyethylene (1957). *Synthetic diamond (1957). Use of gibberellin in agriculture (1958). Stereophonic record (1958). Civil aviation jet aircraft for transatlantic trips (1958)

Remark. The year of the event is in parentheses. The asterisk is used to mark successes achieved earlier than might be expected. Italics indicate achievements of science and technology which were not predicted.

This circumstance can be illustrated by the summary table of scientific and technological progress in the 1950's (Table 8) compiled by I. D. Ivanov from data in the American magazine "Fortune" for January 1959, relating mainly to postwar forecasts of our time. Below we will also give prediction data on the development of science and technology in 1959 and 1960, published in the same source.

Forecasts of the Development of Science and Technology in 1959 and the Beginning of the 1960's

Synthesis of chlorophyll

**25 MeV accelerator

**Operations on animals with "artificial heart" equipment

Machine translation

Predetermination of sex at conception

**Flight at a speed of 3600 miles/hour

**Satellites on the Moon, Mars, Venus

**Rocket with a lift of one million pounds

**Battery-powered television

**Communications by satellite

**Ultrasound cleaning

Thermal electroelements

**Merchant ship, aircraft carrier, and aircraft with atomic engines

**Fuel elements

Middle 1960's

Radiotelescope investigation of the "edges" of visible portion of the Universe

Borehole to the boundary of the Earth's core

Achievement of a temperature of 100,000,000°C

**Antimissile missile

**Manned satellite

**Electronic computer with superhuge memory

**Military vertical takeoff aircraft

Essential improvement in weather forecasting

**Radiation treatment of foodstuffs for prevention of spoilage

**Gas turbine on motor vehicles

**Illuminating panels for homes

End of the 1960's

Synthesis of insulin

Controlled mutation of plants and animals

Direct experimental conversion of nuclear energy into electrical

Vast achievements in the treatment of cancer, arteriosclerosis, and mental disorders

****New polymer materials, alloys, and ceramics**

Electronic blocking on the highway

****Television sets suitable for hanging on the wall**

****Communication satellites**

****Piloted spaceship**

Remark. The sign ****** indicates predictions which have been validated at the present time.

Forecasting and calculation of prospects for scientific and technological progress take on ever greater value in mathematical models of the growth of production, developed by contemporary econometry. One of the Cobb-Douglas functions used with confidence by bourgeois economists [70] has the following form:

$$P = CK^a N^b e^{rt},$$

where P is the volume of the gross national product; C is a proportionality factor normalizing over the various branches; K represents the amount of capital of the investigated branches of industry; N is the quantity of labor; e is the base of natural logarithms; a and b are, respectively, the coefficients of partial elasticity of the volume of production with respect to capital and to labor (usually taken as $a + b = 1$, where $a = 1/3$ and $b = 2/3$); r is the annual norm of independent issue of production conditioned by the factors of scientific and technological progress; and t is time. For the period 1922-1939 in the scales of capital production of the Western European countries, r comprised a quantity of 0.13% per year [71]. Now it is taken as equal to 2.25% and even 3.38% per year [70].

In the Stone-Brown econometric model, developed for forecasting by English economists, it is proposed that such a coefficient be derived not by extrapolation from the past (this is reasonable,

especially considering the instability of the capitalist economy); but by computation on the basis of independent forecasts of an evaluation of requirements and trends of future developments. "It is important to keep constantly in mind," write the authors of the model, "that the connections and coefficients of the model be oriented to the future, and not to the past or present. There is no way that any purely econometric technique based on analysis of past industry could fully satisfy us. In this connection we emphasize in particular the need for cooperation of the research efforts of economists, statisticians, and engineering and technical personnel" [72].

This important and complex methodological problem still awaits its solution. At present the evaluation made in 1962 by the outstanding American economist R. Heilbroner remains in force: "We still do not have an acceptable theory of scientific and technological progress and the changes connected with it, and even to a lesser degree - a theory of universal technical and economic models" [74].

In recent years the problems of scientific and technological forecasting have attracted ever more constant attention of Soviet economists [75, 76, 77]. It is known [78] that about 3/4 of the growth of productivity of labor and more than 1/2 of the reduction in cost of industrial production in the USSR is achieved through measures aimed at realizing scientific and technological progress in production. It has been calculated that if we introduce into the designing of new coal establishments the methods which take into account the basic forecasts on specific prospects for development of coal-mining technology ("Library of Characteristics of Future Equipment"), the reduction in the volumes of work on subsequent reconstruction of these establishments and the optimizing of their operating conditions can result in savings on the order of 80-100 million rubles per year on the scale of the coal industry of the UkrSSR alone. This is approximately equal to the volume of capital investment in the construction of two new coal shafts with an annual productive capacity on the order of one million tons*. Specialists are turning their

*The evaluation was made together with DONUGI coworkers A. M. Arabadzhev and O. F. Shukin.

attention also to the fact that accelerating by one year the rates of mastering new results of science and technology accumulated in the USSR can give a total national economic effect on the order of 5-6 billion rubles*.

In the conditions of Socialist society, creatively striving to construct its entire life on a truly scientific basis, scientific and technological forecasting has the fundamental nature of a prospect for acquiring an objective character and reflecting the public interest. The economic reforms now being accomplished in many Socialist countries present new urgency in the requirement for sound scientific foundations and flexibility for the leadership; they intensify the role of economic factors in the methodology of scientific and technological forecasting, stimulate orientation of forecasting toward a definite path of more rapid growth of productivity of labor and increasing the profitability of public production on the basis of realizing promising directions of scientific and technological development.

The experience of realizing measures for accelerated scientific and technological progress of production in conditions of economic reform attests to the fact that the possibilities found in the new system of management are far from completely used at present. "Some economists and managers fear," noted S. M. Yampol'skiy, "that the charging of funds and incentives primarily according to an index of profitability can reduce the rate of introducing new equipment and slow technological progress. There are cases of rejecting earlier-ordered equipment. This phenomenon has two sides: a positive side, when an enterprise reduces baseless orders for equipment and ensures further growth of production by the best use of existing equipment, and a negative side, when fear of a drop in profits results in rejecting required renovation of equipment" [78].

*This is the evaluation of V. F. Fomin, a specialist of the Goskomitet of the CM of the USSR.

Solution of this problem is possible only on the basis of a complex of measures rooted both in traditional economic levers (price policy, interest rates, order of calculation and distribution of profits, the system of planned production indices, stimulation and material provision for measures of scientific and technical progress, etc.), and also in the newly formulated methods of future planning, economic and scientific and technical forecasting.

We share completely the point of view of Soviet economists, according to which "national economic forecasting represents the unity of fairly independent complex problems, each of which has its own intrinsic content, along with external connections and relationships joining the different parts into a unified system" [76].

A list of complex problems of national-economic forecasting, in which scientific and technological forecasting was assigned an exceptionally important place, was formulated in the recommendations of the scientific meeting "Methodological Problems of Long-Term Economic Forecasting," held in 1966 by the Gosplan of the USSR and the Academy of Sciences of the USSR. They are outlined below [79].

Economic aspects of scientific and technological progress. In studies of this area the scientific and technological problems of different classes should be separated; these include problems which, in principle, are of a completely new type and have particularly long-term value - for example, in the field of high-energy physics - as opposed to problems of the near future. It is necessary to develop economic indices which reflect the influence of scientific and technological progress on production, elevation of its effectiveness, and the needs of the population.

Economic aspects of forecasting natural resources. Study in this area proposes to evaluate natural materials (useful minerals, soil, fresh water, forest wealth, resources of the oceans, rivers, etc.) and the possibilities of involving them in public production. Here the forecasting of natural resources should, in principle, precede development of actual economic forecasts.

Economic aspects of forecasting population and its rational employment. The development of these problems must be based on simulation of demographic processes, studies of population migration and its directions, analysis of labor resources as a whole over the country and their makeup with respect to economic regions, and study of the conditions for increasing the effectiveness of utilization of labor resources.

The problem of reproduction of capital funds and capital investments. Here it is necessary to study the following: resources, technical parameters, structure, and growth of capital industrial funds and clarification of reserves for their better use; the composition of nonindustrial capital funds; the scale, structure, and degree of use of revolving funds and the possibility of better expenditure of raw materials, materials, energy, waste products, etc. Besides this, it is necessary to provide analysis of the investment process in the USSR - to uncover its role in realizing long-term programs of scientific and technological progress.

Then there are the problems of consumption and living standards of the population, economic requirements of external trade, financial aspects and prices, summary problems of the dynamics of the national economy, problems of forecasting development and arrangement of the branches of the national economy. Solution of the main branch, regional, and large inter-branch problems is recognized as one of the most important tasks of research work on economic forecasting.

At all steps and stages of forecasting account should be taken also of the principal circumstance that from the point of view of complex prediction the prospect of socioeconomic development of scientific and technological forecasting is extremely important and specific, but nonetheless it is only a structural element of a broader system. In view of such a position (Fig. 19), an urgent need exists for complex connection of forecasts of the development of science and technology with prospective resources and development of the economy and social life of the country predicted by various special methods. Solutions which are made on the basis of predicted data should

correspond to the social goals of our entire society. Therefore they must be balanced with the economic and scientific potential of a region (the nation, a republic, a zone, etc.) and with the mineral raw material, power, productive, and demographic resources.

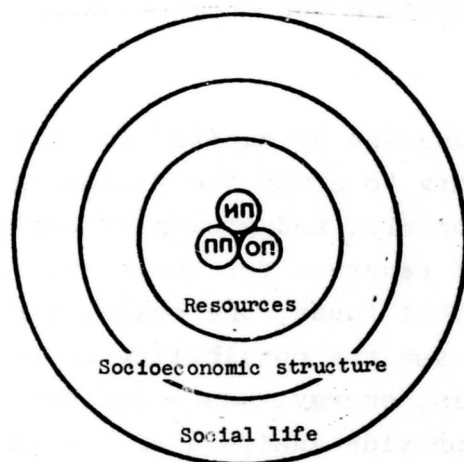


Fig. 19. Position of scientific and technological forecasts in the structure of complex prediction of the future.

In the cited circumstances there appears not a formal, but a deep methodological connection of scientific and technological forecasts which are specific in their form and purposes with economics and a broad circle of problems of social and economic forecasting.

3. Forecasting and planning in control of scientific and technological progress

Increasing the standard of living of the people and guaranteeing the economic, defense, and scientific and technological potential of the country comprise the essence and content of the basic goals of Socialist production. The entire matter of controlling scientific and technological progress in the Soviet Union is oriented toward ensuring rapidly growing public requirements. Here the *main economic problem* of our country at the contemporary stage of development was formulated by the XXIII Congress of the CPSU as follows: "On the basis of the manifold utilization of achievements in science and technology,

industrial development of the entire public production, increasing its effectiveness and the productivity of labor, to ensure the further significant growth of industry, a high stable rate of development of agriculture, and thus to achieve an essential raising of the standard of living of the people, the most complete satisfaction of material and cultural requirements of the entire Soviet people"*.

Thus, scientific and technological progress is assigned one of the leading places and guiding roles in the solution of the major economic problem of our nation. Soviet science can justify these hopes of society only on the basis of mastery of the principles of planned development and scientifically founded methods of control of the entire spectrum of scientific progress -- from fundamental research and exploratory works through applied research and experimental design development up to mastery of the production of new and more progressive objects of scientific and technological progress [80, 81].

In converting into a directly productive force, science regularly and ever more urgently requires scientifically based approaches to the realization of each of the basic functions of control of scientific and technological progress: the selection of goals and planning, organization of performance, distribution of resources, analysis and monitoring of the course of performance, timely inclusion of controlling actions corresponding to the goals and situation (correction of goals, plans, and performance organization, redistribution of resources, introduction of new performance incentives, perfection of methods of monitoring and types of responsibility).

Scientifically based control is assigned the task of optimizing the proportions and development of individual subsections of scientific and technological progress and ensuring the maximum results with the resources and capital investments available under the conditions of a given country.

*Materials of the XXIII Congress of the CPSU. M., Politizdat, 1966, p. 228.

There is one very significant sign which singles out scientifically well-founded and effective control from actions which are similar in form but are more accurately called corrections. This criterion is the timeliness with which decisions are made and with which one or another controlling action is taken. In order to better clarify the dependence of effectiveness of control of scientific and technological development on the timeliness and tardiness of decisions, we shall turn to the following example.

It is known that the effectiveness of any direction of scientific research or technical development is characterized by alternation of periods of accelerated growth with periods of relatively slow rates in obtaining new positive results. Such changes were evident in the rates of discovery of new chemical elements, increasing the power of elementary particle accelerators, growth in the efficiency of railroad prime movers, aircraft speeds, etc. (see Figs. 2, 14, 15, 16)*. In each case a new rise required transition to new methods of research, or to new principles of acceleration of particles, or to engines of types which were new in principle.

Figure 20 shows that if a suitable type of decision is made and realized in a timely manner, the decisive prerequisites for ensuring total effectiveness of scientific and technological policy are created. The points $M_1 \dots M_4$ on the diagram designate the moment of bending of the curve of growth of results, after which development along new directions follows rapidly, so that at the moment when old capabilities are exhausted the new approaches provide the required force. Points C and E designate situations with clearly expressed unsatisfactory results of scientific and technological development. Solutions made in these conditions are already too late**. Their realization amounts

*In the theory of "growth curves" developed by the contemporary science of measurements, such regular processes are characterized by enveloping curves or, to be more exact, by a system of exponents with different values of growth coefficients (hypothesis of V. V. Nalimov and Z. M. Mul'chenko) [168].

**W. Rekus, a forecaster from the GDR, considers on the basis of a similar approach that it is possible to evaluate the summary effectiveness of forecasts introduced into the practice of control of scientific and technological development [82].

of connection); forecasting is used for analysis of the course and prospects of fulfilling specific plans; and the aftereffects of fulfillment or nonfulfillment of plans for scientific and technological development are predicted.

Contemporary scientific forecasting has not only significantly expanded the region of its application and incomparably refreshed and renewed the arsenal of methods for predicting future science and technology. No less important is the fact that forecasting has taken on the character of a systematic comparative analysis of trends and levels of development, continuous evaluation and refinement of prospects. On the basis of completely understood objective laws and trends of development, it makes it possible to formulate alternatives for development and to evaluate the conditions required to achieve different possible goals. Thorough development of predicted variants of development is one of the most important elements for improving the scientific foundation of plans.

However, with all the value of forecasting it is obvious that no matter how perfect the scientific and technological forecasts, some of the data obtained with their help will still be insufficient to make decisions in the form of state plans for scientific and technological development — an even more so in the case of plans for agriculture and plans for achieving prospective social goals of social development.

Scientific and technological forecasts, as we have already noted, comprise a subsystem which is specific with respect to objects, goals, and methods within the broader system of forecasts which includes the forecasting of natural and demographic resources along with economic and social forecasting. Information obtained from all types of forecasts is analyzed critically and is used during the compilation of state plans along with other data which reflect national and international interests, the political circumstances of the government, etc.

The concept of scientific and technological forecasting as one of the most important prerequisites is soundly scientifically based;

particularly in the case of prospective planning, it has found broad state application in our country in recent years.

In 1965, addressing the meeting of the Gosplan of the USSR, the President of the Council of Ministers of the USSR A. N. Kosygin stated: "Can we, in our agricultural plans, ignore the soundly based forecasts relating to the future? No, we cannot. Planning - this is a science which should absorb all scientific and technological achievements and progressive ideas. Otherwise the plan will not be responsive to the assignments which are set by the Party and the Government. Therefore discussion of scientific forecasts must precede the development of plans for the development of branches of the national economy.... We must have at our disposal scientific forecasts on the development of each branch of industry in order that we know beforehand the forward, progressive path - to know in which direction to develop the plan" [83].

It is important to emphasize that the concept being developed in our country of scientific and technological forecasting is recognized also in connection with the planning of fundamental and theoretical research to be conducted by the collectives of scientists of the Academy of Sciences of the USSR and at the Academies of Science of the Union Republics. In 1968, addressing the general assembly of the Academy of Sciences of the USSR, the President of the Academy M. V. Keldysh noted: "...forecasts of the development of the most important branches over more prolonged periods are taking on greater significance. Five-year plans must not only solve problems of the given five-year period, but must also prepare future development" [84].

Obviously, in the future forecasting will make it possible to turn our current five-year plans into stages of achievement of broader (10-15 years) prospects, fixed in accordance with long-term plans of scientific, technological, economic, and social development.

With respect to problems of complex exploratory research, the President of the Ukrainian Academy of Sciences, B. Ye. Paton, emphasized the role of forecasting in the analysis of the prospects and evaluation

of the importance of different research works and their specific stages [80]. However, as he accurately noted, "the organization of scientific forecasting, especially in the sphere of development of the most important complex fundamental research, is still in an unsatisfactory state here. It is for precisely this reason that the Ukrainian Academy of Sciences is undertaking specific steps in this direction: scientific collectives are being created which have begun work in the field of the methodology of science and scientific forecasting"*.

In the last 3-4 years the business of scientific and technological forecasting has developed at a clearly accelerating pace in the USSR. Scientific symposia on this problem conducted in 1966-1968 in Kiev and in Moscow drew the attention of thousands of participants from practically all centers of scientific and technological progress in our country. On the level of branch scientific research institutes and main design and construction organizations, and also in the structure of many branch institutes of scientific and technical information and technological and economic research we see everywhere the creation of the laboratory and the group of specialists professionally occupied with analysis of trends, comparative evaluation of levels, and forecasting of scientific and technological development.

Work on scientific and technological forecasting is taking on an ever more complex character. We have seen a ripening of urgent requirements and of real possibilities for uniting them into a single harmoniously operating system. A proposal** for a system of this type for interconnected forecasts of work on a nationwide scale is illustrated by the sample diagram shown in Table 9. A different

*For solution of these problems there was created a special scientific subsection - The Department of Complex Problems of the Study of Science, under the Council on the Study of Productive Forces of the UkrSSR, Ukrainian Academy of Sciences; its composition includes structural research departments - theoretical fundamentals of the study of science, scientific and technological forecasting, analysis of scientific potential, economic science.

**Developed by a group of specialists at TsNIIPI [Central Scientific Research Institute of Patent Information and Technical and Economic Research] (R. P. Vcherashniy, V. A. Obukhov, et al.) [65]. Presented here with our additions.

possible scheme of organizing the cooperation of collectives accomplishing the development and utilization of different types of forecasting materials is presented on Fig. 21. This proposal* relates to specific conditions in the Ukrainian SSR. However, in our opinion its basic idea can be interpreted and applied on a broader scale.

On the tentative diagrams presented, the system of connections, forecasts, and plans called upon to cooperate to increase the effectiveness of total state plans for the development of the national economy of the USSR is clearly evident; these plans include the realization in action of a single nationwide scientific and technological policy.

Although the theory and existing experience of scientific and technical forecasting are still far from perfection, the contemporary level of knowledge in this field permit (and the actual requirements of life make urgent) the realization of broadly stated practical works on forecasting the most important directions of scientific and technological progress.

The complex forecast organized by the Goskomitet of the Council of Ministers of the USSR on Science and Technology in the region of prospects for development of power engineering, transport technology and transport nets, and also on the fuel and energy balance of the USSR and a number of other urgent national economic problems are deserving of the high evaluation of the community and of specialists. The ever closer connection of research on scientific and technological forecasting with developments of collectives of scientific economists and specialists on social forecasting, noted in our country, can be considered a progressive phenomenon.

*Developed under the leadership of the author by a group of specialists in the Section on Scientific and Technological Forecasting of the Department of Complex Problems in the Study of Science, Ukrainian Academy of Sciences (L. P. Smirnov, Yu. V. Yershov, et al.).

Table 5.

REQUIREMENTS OF SOCIETY

RESOURCES

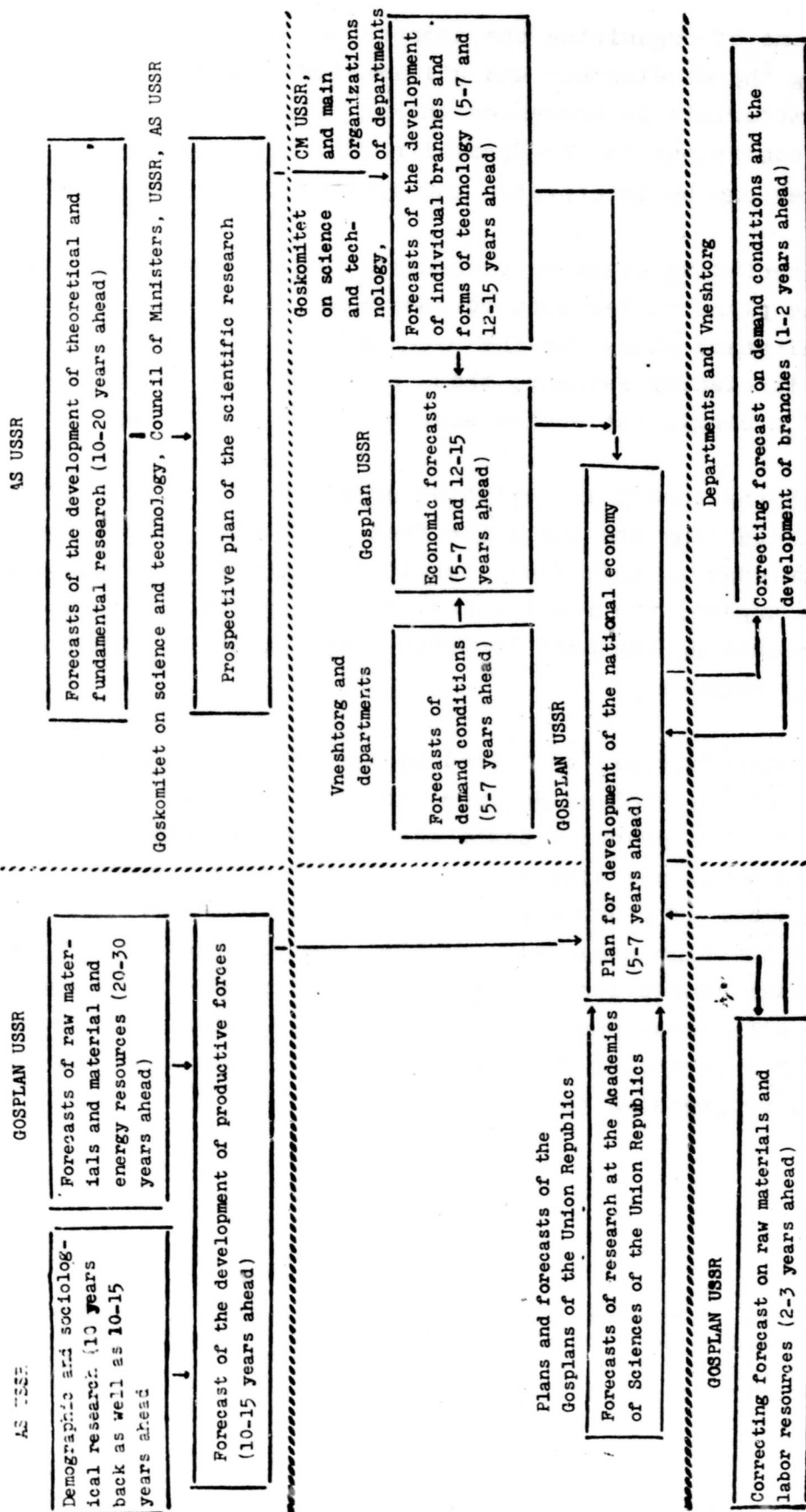
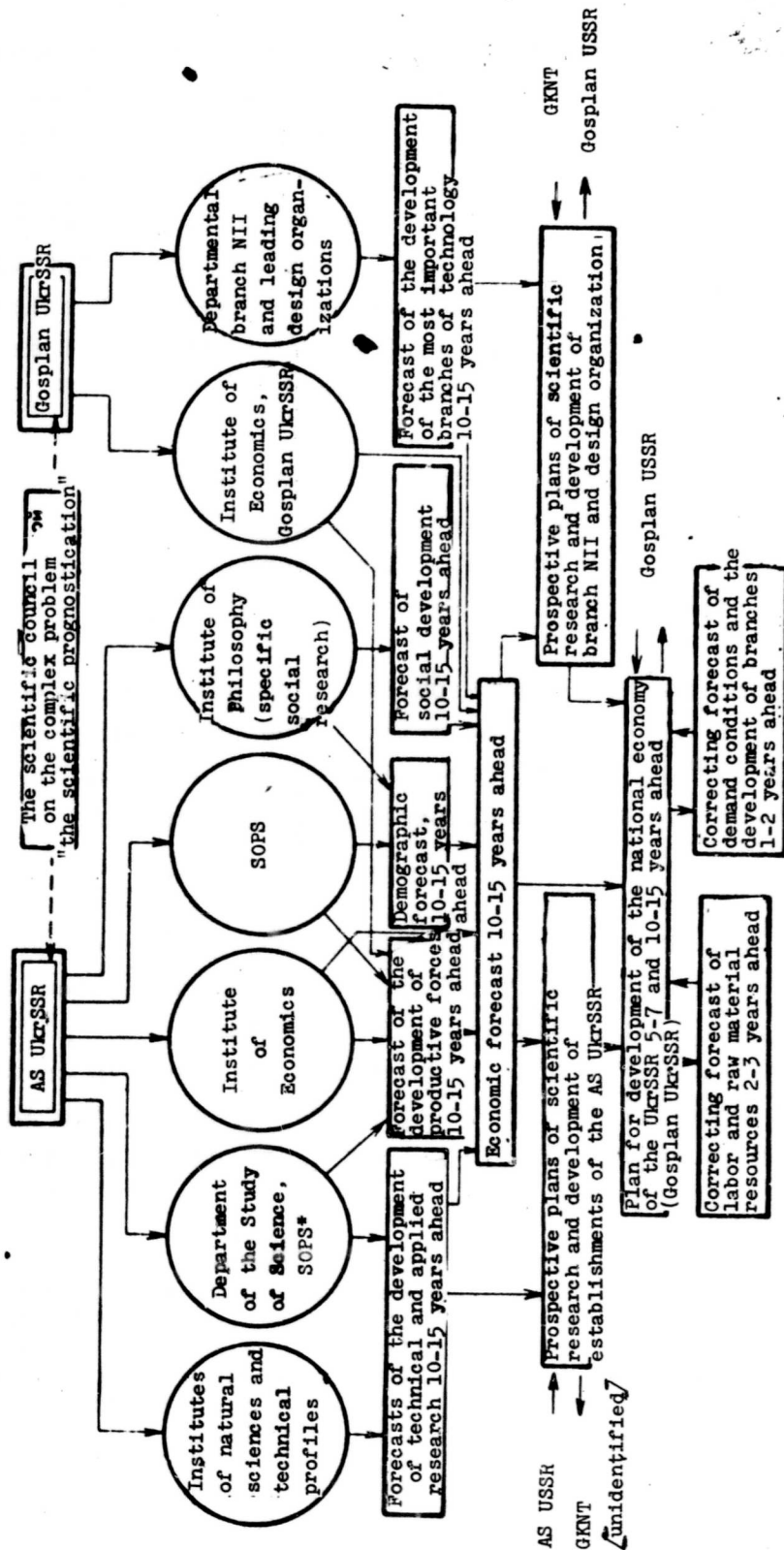


Diagram of the organization and utilization of predicted developments in the UkrSSR



*Council for the Study of Productive Resources.

Fig. 21. Diagram of the organization of forecasting work in the Ukrainian SSR (draft).

Soviet scientists accomplish a broad exchange of experience with forecaster-colleagues from the Socialist countries. International meetings and scientific conferences are held. Forecasting developments are conducted within the framework of the appropriate scientific research programs of the various countries which are participants in the Council for Mutual Economic Aid. We are convinced that in the conditions of the Socialist countries there are special favorable prospects for the creation of a deeply based system of scientific, technological, economic, and social forecasts which will serve the matter of building socialism and Communism*.

In the German Democratic Republic there is substantial experience in complex development of forecasts of national economic development, based on consideration of trends in contemporary scientific and technological progress.

In the Hungarian Peoples' Republic a substantial number of specially created scientific collectives are carrying out the development of scientific and technological forecasting on key problems of the prospective plan for development of the Republic in the period 1971-1985.

In the Bulgarian Peoples' Republic, July 1968 saw the calling of plenary session of the CC of the BCP, specially dedicated to improving the system of controlling society. An important place in its resolutions was allotted to the development of research on the study of science and organization of development of scientific and technological forecasting for long-term planning of the future in

*This collective experience found reflection in the materials of the conference of specialists from member countries of the Council for Mutual Economic Aid and the Socialist Federated Republic of Yugoslavia on exchanging experience and compiling scientific and technological forecasts (Prague, February 1967) [85], and materials of the combined Soviet-Czech symposium of leading specialists of the state committees on science and technology (Moscow, January 1968), and also in the especially broad and valuable materials of the Scientific Symposium of CMEA on the Problem "Control, Planning, and Organization of Scientific and Technological Research" (Moscow, May 1968). The latter works were published in a special collection.

Bulgaria (15-20 years) [86]. A plan of the organization and inter-connection of forecasting works in the PRB, compiled* in accordance with the resolution of this plenary session, is shown on Fig. 22. The proposed scheme, naturally, reflects the formulated specialization of functions and the responsibility of different levels of administration of the PRB.

In recent years the business of scientific and technological forecasting has assumed large dimensions in a number of the major capitalist countries. In reviews of these works [22, 87] we find data on hundreds of specialized organizations which carry out forecasting and of thousands of industrial firms and specialized institutions which use the predicted developments. In recent surveys we note that the magnitude of expenditures on forecasting is of the order of 2% of the total funding for research and development and that a 50-fold return is obtained from timely use of soundly based prediction evaluations in making decisions in scientific and technological policy [88].

In capitalist countries forecasts are used as one of the indispensable bases for long-term and short-term development programs. Most frequently such programs are developed on the scale of individual firms or monopolies, but in recent years work has been carried out in the field of programs which are nationwide in scale, in particular those covering military technology or key economic problems [89].

Like any other development in the progress of scientific and technical thought, the business of forecasting science and technology develops in capitalist countries in an unhealthy social and psychological climate. The prospects of mass unemployment in connection with automation of production and of many types of labor in a service

*The plan of the basic positions on organizing scientific and technological forecasting in the PRB was compiled at the request of the Goskomitet of scientific and technological progress of the PRB under the leadership of the author of this book together with the Bulgarian specialists V. Ivanov and B. Benev.

field, the danger of the use of the newest achievements of chemistry and biology against humanity, the absence of any ability of society to exert effective control over the inevitable military utilization of many achievements of scientific and technical progress — all of this cannot help but be reflected in the attitude of scientists in capitalist countries toward the determination and selection of prospects of development of science and technology.

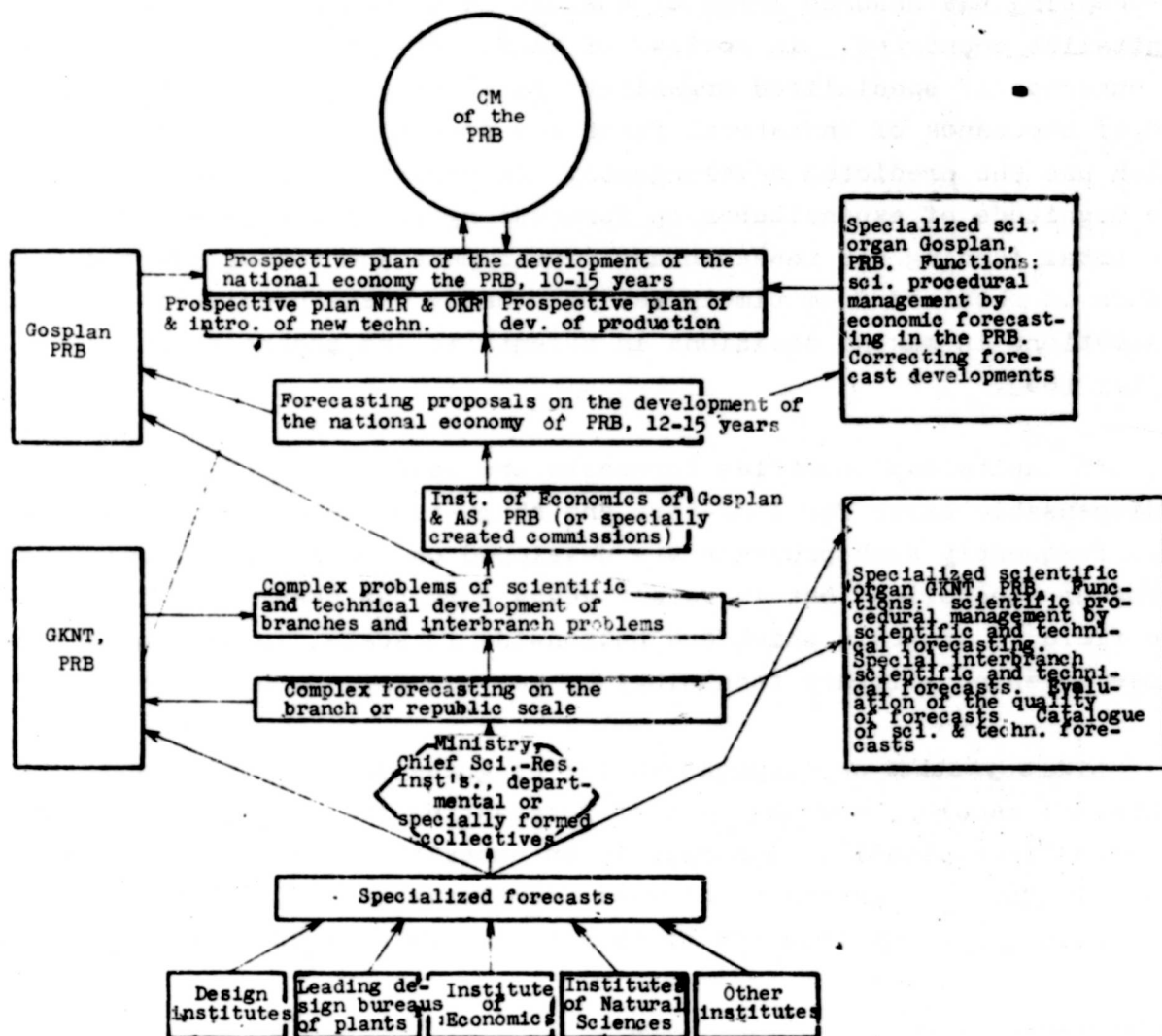


Fig. 22. Plan of the organization of development work on scientific and technical forecasting in the Peoples' Republic of Bulgaria.

Even more important and, in its own way, a determining influence on the nature of scientific and technical forecasts developed in capital countries is the so-called set of "national goals" formulated by the capitalist state and the huge monopolies with respect to the progress of science and technology; these goals are established by them as the criteria for selection of possible variants of development. The purpose — this is one of the most important conditions of scientific and technical progress. It is precisely here where we find the watershed in the nature and social functions of scientific and technological forecasting in the Socialist and capitalist countries.

Symptomatic in this connection, for example, is the effort of a number of capitalist governments to put scientific and technical forecasting in the service of strategic reconnaissance and the openly military departments. The use of methods and of specialized firms of scientific and technological forecasting for purposes of industrial espionage and counterespionage carried out by capitalist firms and industrial monopolies competing against one another are ever more frequent* [90].

The most important final purpose of scientific and technological forecasting under the conditions of a Socialist state is assistance in selecting the most promising goals of scientific and technological development, those ensuring to the highest degree the growth of the materials and spiritual wellbeing of the laboring class of the country, and also optimizing the methods of achieving these goals. This type of serious practicality can be achieved only on the basis of profound theory and creative generalization of the world experience in forecasting**.

*This is discussed quite openly, in particular, in the book by V. Platt [17].

**In this connection there may be special interest in publications which are listed with bibliographic information in the list of references appended to this book, as well as material being systematically published by three principal foreign magazines on scientific forecasting: "The Futurist" (Washington), "Futures" (Guildford, England), and "Futuribles" (Paris).

It can be said with complete certainty that the era of amateurism and of efforts to solve the problem of scientific and technological forecasting by means of temporary commissions and periodic conferences has outlived its usefulness. Systematic theoretical, experimental, and applied development of the problems of scientific forecasting is required now. In brief, the time is come to give the matter of scientific and technical forecasting an important state character. We are convinced that in the course of realization of the Resolution of the Central Committee of the CPSU and the CM of the USSR "on measures for increasing the effectiveness of work of the scientific organizations and the accelerating of the utilization in the national economy of the achievements of science and engineering" Soviet scientific forecasting will justify the hopes held for it, deepen its theoretical base, and considerably raise the effectiveness of the methods of forecasting the future of science and technology.

CHAPTER IV

CONTEMPORARY METHODS OF SCIENTIFIC AND TECHNOLOGICAL FORECASTING

At the present time scientific forecasting counts more than 130 methods and applications of forecasting scientific and technological development, differing in level, scales, and scientific foundation. Also a number of schemes of classification of these methods have been proposed [9, 11, 22, 44, 87]. With all the diversity of methods of scientific and technological forecasting, it appeared to us to be most advisable, from the practical point of view, to reduce them to three basic classes (extrapolation methods, expertise methods, and simulation methods); each of these includes several types and characteristic groups of methods of scientific forecasting (Fig. 23). We shall briefly examine the basic ideas and specific capabilities of these methods in order to evaluate their suitability for exploratory, program, and organizational forecasts.

1. Extrapolation methods

The oldest hypothesis about the future is the idea of it as a straight and direct continuation of the present. All extrapolation methods are based on the assumption of the immutability or at least relative stability of existing development trends. It is possible to extrapolate trends which are formulated on the descriptive level, but most frequently this is done with respect to statistically accumulating trends of changes in one or another quantitative characteristic of science, technology, and the organizational system of science.

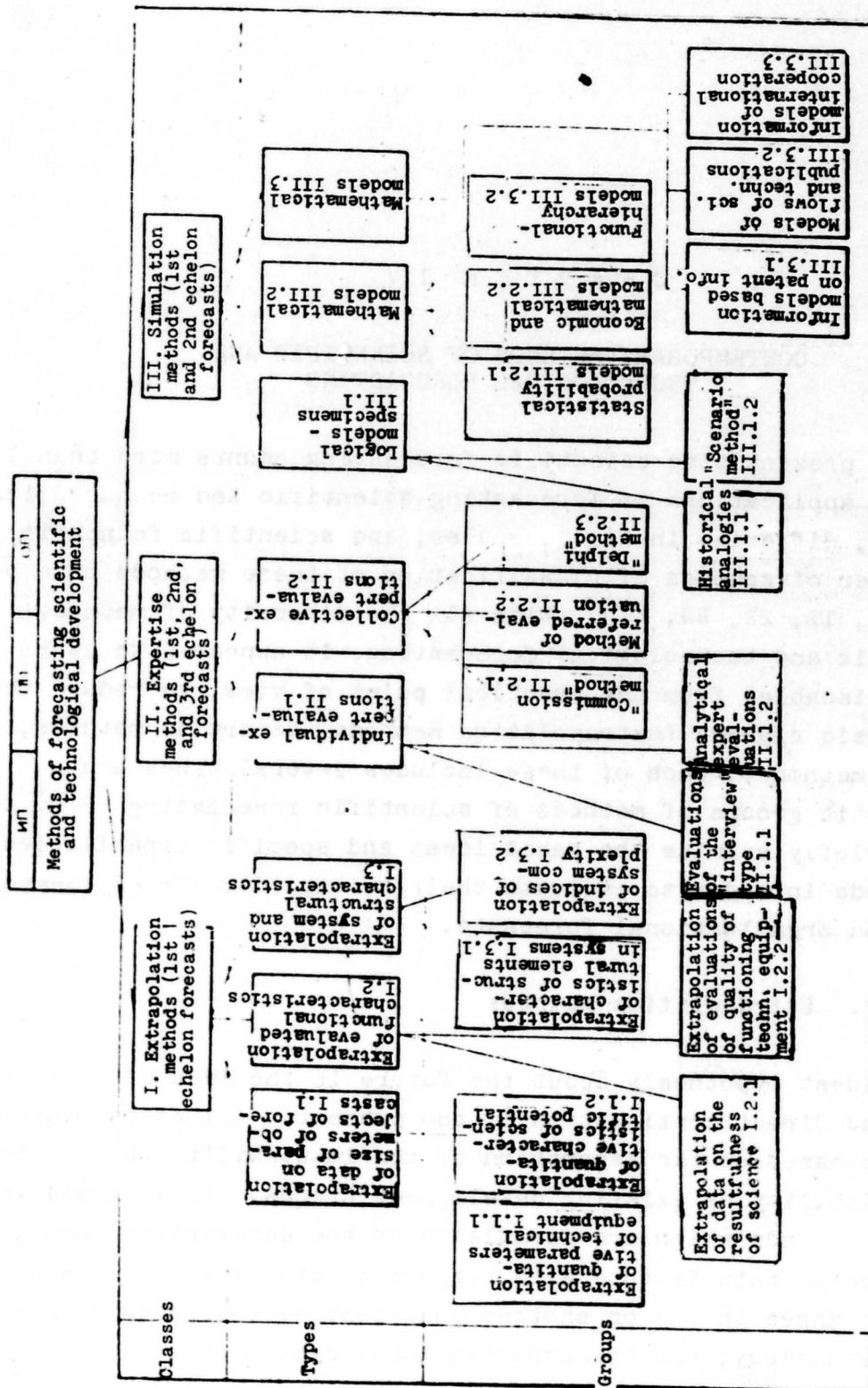


Fig. 23. General classification of methods of scientific and technological forecasting.

The degree of reality of forecasts of this type and the measure of confidence in them are conditioned to a decisive degree by the reasoning behind the selection on the limits of extrapolation and by the stability of correspondence of "gauges" with respect to the essence of the phenomenon under consideration. These gauges frequently turn out to be noncomparable in large time scales - the area of the second and third echelons of forecasting. In such cases extrapolation frequently leads to debatable or even absurd results. Here are several examples.

Beyond the limits of the upper boundary of the second echelon, forecasts of the exponent of growth of the number of scientists passes through the point of the expected number of the population of the Earth. If we extrapolate an unchanged total trend in the growth of speeds of transport means (see Fig. 15), by the end of the century a value can be obtained which is close to the speed of light [91]. It has also been calculated that by 1990 the total number of artificial Earth satellites (with an unchanged rate in the growth of their number) will exceed a million....

The preliminary formulation of basic logical hypotheses which penetrate to the "physical" essence of the processes being extrapolated and exposure of cause-effect relationships in phenomena being studied by means of statistics on the basis of contextual analysis - these are all mandatory conditions for correct, and also frequently simple, elementary, proper utilization of the apparatus of mathematical statistics. It is appropriate to remember the warning made by F. Mills, a statistician with a worldwide reputation: "Statistical proof in itself does not establish causality. Statistics establishes the degree of covariance, but whether causal relationships exist or not and what means can be used to develop them cannot be established by statistics" [92].

When extrapolation methods are used in scientific and technological forecasting, a direct consequence of this requirement is the need to calculate factors of public demand for new scientific and technological developments, evaluation of the influence on the

development of the forecast object of price policy and the socioeconomic and production conditions which are specific in different countries.* Thus, for example, the statistics of technical decisions in dry-cargo marine transport of Japan and its major trading partners attest clearly to a trend toward creating "supertonnage" ships. The juncture of import and export of raw materials by marine transport in the USSR differs in principle from the situation occurring in Japan. This circumstance renders invalid the extension of conclusions from extrapolation of such data to the corresponding technical decisions of Soviet ship-building.

One additional important procedural circumstance of the considered examples of forecasting is the selection of the depth of the retrospective aspects of the extrapolated trend (base of extrapolation) and the range of the extrapolated interval. A. S. Konson considers it possible to take them as equal [93, 58]. V. A. Lisichkin recommends taking the interval of forecasts as equal to 1/3 of the considered series of data [94]. The last proposal seems to us to be more suitable, although its foundation is mainly empirical. A useful base point in this case will be preliminary qualitative evaluation of the stability of the process and the nature of the laws determining it.

In each case the selection of parameters which characterize the technical level of the given object is worthy of special discussion. As an example, indices used in practice during analysis of trends and forecasting of the technical and economical level related to such a technical object as electronic computers are given below.

*A thorough outline of extrapolation methods which take into account the factors of demand and price is given in the last work of A. S. Konson and V. S. Sominskiy [58].

Types and quantities of output signals, mA, V	Capacity of auxiliary storage, number of words
Speed of addition, op/s	Guaranteed service life, years, months
Speed of multiplication, op/s	Dimensions, m ³
Capacity of fast store, number of words	Production per one failure, hours
Capacity of permanent storage, number of words	Total weight, kg
Bit configuration of numbers (commands), number of units	Required power, kVA

Attention should be paid to the fact that the complex objects of contemporary technology cannot, as a rule, be characterized by a single parameter. For example, the popular characteristic of operating speed of an electronic computer cannot in itself give a basis for any evaluation conclusions without consideration of the purpose and structure of the computer. Thus, the specialized machine "Mir," with a comparatively low operating speed, in practice is more effective during solution of its own class of problems than the significantly faster all-purpose Soviet and foreign computers.

Obviously, in each such case specially based systems of technical characteristics will be required.

With consideration of the material outlined above, our presentations* on the sequence of actions during statistical analysis of trends and extrapolation can be outlined as follows.

1. Clear definition of the problem, advancing of hypotheses about the possible "mechanism" of development, discussion of factors which stimulate development of the given object and of those which prevent it.
2. Selection of a system of parameters, unification of different unit measurements relating to each parameter individually.

*Together with L. S. Stoykova.

3. Collection and systematization of data. Before they are summarized in tables it is appropriate once again to verify the homogeneity of the data and their comparability; this includes breaking down the information with consideration of the time factor (some data relate to lot-produced articles, while others may characterize only objects in the design stage or outlined scientific and technological possibilities).

4. Exposure in the course of statistical analysis of these data of trends or symptoms of changes in trends of development of the studied quantities. The following approach to solution of this problem is reasonable.

Plot the values of the studied parameter which correspond to the given time on a semilog coordinate grid (parameter values on the y-axis with a logarithmic scale; time on the x-axis with a uniform scale). We obtain a certain field of points. Then it is proposed that the curve

$$\ln y = a_0 + a_1x + a_2x^2 \quad (1)$$

be drawn in this field in such a way that the sum of the squares of deviations of initial points from the points of this parabola becomes minimum*.

Why in many cases is it wise to select just this sort of regression curve? We will recall that all the considerations following below relate to the study of a special type of trend — for example, constantly growing or constantly diminishing.

Forecasting by the extrapolation method ordinarily consists in the fact that the relationship $y = f(t)$ obtained by one or another method will usually contain the date t of interest to us and will provide a means for finding the corresponding values of y , which are taken as the forecast for the given year. In this case for a sound

*In accordance with this criterion, naturally, a different type of approximating curve can be selected.

foundation of the forecast it is necessary to prove the following: that the law (trend) found on a certain interval does not change outside it within determined boundaries; that the parameters themselves do not change qualitatively.

Ordinarily the inertia of the predicted system is used as a prerequisite for the proof. It is considered that in complex systems changes occur comparatively slowly; therefore one can expect that errors of extrapolation for small time segments will be insignificant. Such a prerequisite is not sufficiently strong. For a forecast it will frequently be interesting and important not so much to predict a specific value of the studied parameter in a certain year as to provide a timely fix of objectively noted shifts and symptoms of changes in trends of development.

During smoothing of the initial data of the parabola, cases may be noted of a minimum and maximum of the approximated data. Another advantage of the parabola as a leveling curve is the fact that it smooths the initial data more exactly than a straight line and contains three (comparatively few!) parameters, which are easily found during solution of a system of three equations with respect to these parameters.

5. The stage of direct production of calculations. Below we present calculation tables and formulas for finding coefficients of a system of equations in the general case. Let $y = y(t)$ be the values of the investigated parameter which correspond to time t . We shall designate $\ln y = \tilde{y}$ and $t - t_0 = x$, where t_0 is the new point of beginning of reading. We shall examine the case when several \tilde{y}_{k1} , $1 \leq k \leq l_1$, l_1 correspond to one x_1 ; that is the number of \tilde{y} corresponding to x_1 . We shall designate $\sum_{i=1}^{l_1} \tilde{y}_{ki} = z_1$. Then condition (1) is written as

$$f(a_0, a_1, a_2) = \sum_{k=1}^n \sum_{i=1}^{l_1} (\tilde{y}_{ki} - a_0 - a_1 x_i - a_2 x_i^2)^2 = \min \quad (2)$$

For this it is necessary that

$$\frac{d}{dz_0} = 0, \quad \frac{d}{dz_1} = 0, \quad \frac{d}{dz_2} = 0.$$

Having developed these conditions, we obtain the following system of three equations for a_0 , a_1 , and a_2 :

$$\left\{ \begin{aligned} Na_0 + a_1 \sum_{i=1}^n l_i x_i + a_2 \sum_{i=1}^n l_i x_i^2 &= \sum_{i=1}^n z_i; \quad N = \sum_{i=1}^n l_i; \\ a_0 \sum_{i=1}^n l_i x_i + a_1 \sum_{i=1}^n l_i x_i^2 + a_2 \sum_{i=1}^n l_i x_i^3 &= \sum_{i=1}^n z_i x_i; \\ a_0 \sum_{i=1}^n l_i x_i^2 + a_1 \sum_{i=1}^n l_i x_i^3 + a_2 \sum_{i=1}^n l_i x_i^4 &= \sum_{i=1}^n z_i x_i^2. \end{aligned} \right. \quad (3)$$

The calculations for the coefficients of the system are conveniently arranged in a table:

Table 10.

1	2	3	4	5	6	7	8	9	10	11	12
l_1	x_1	x_1^2	x_1^3	x_1^4	z_1	$x_1 z_1$	$x_1^2 z_1$	$l_1 x_1$	$l_1 x_1^2$	$l_1 x_1^3$	$l_1 x_1^4$

The sums of the first and the 6-12th columns give the corresponding coefficients of equations of the system; the system is solved by known methods.

6. Making a final decision on selection of the limits of extrapolation. By altering the time variable we obtain values of the approximating curve on the extrapolated segment of future development.

7. Critical evaluation of the obtained extrapolation data from positions of previously developed hypotheses and logical foundations. The statistical error of forecasting - h_{np} - is fixed. For its evaluation we can use the known formula

$$h_{np} = \sqrt{\frac{\sum_{i=1}^n \sum_{k=1}^l \tilde{y}_{ki} - y_i^2}{\sum_{i=1}^n l_i}}.$$

where \tilde{y}_{ki} are experimental points; $y_i = a_0 + a_1 x_i + a_2 x_i^2$ are points

of the smoothed parabola; l_1 is the number of experimental points for the i -th abscissa; n is the length of the initial time interval.

This is not the only mathematical method of evaluating errors and possible variations of the data of a statistical analysis and extrapolation. The main thing, however, is that the forecaster use common sense.

A truly scientific attitude toward extrapolation of trends has nothing to do with fatalism or with blind admiration when faced with statistical evaluation. Even extending extrapolation to the "point of absurdity" - to impossible or completely unsuitable situations - is not a totally senseless occupation if we consider its results not as a forecast in themselves but as evidence of more or less acutely maturing requirements to change a trend previously developing. Besides this, during extrapolation of a system of mutually connected parameters there is the possibility of evaluating the sensitivity of the final data to changes of different parameters which are equal in scale. On the basis of information thus obtained forecast recommendations are formulated for control of the development process.

Extrapolation is used most frequently and with merited confidence in research forecasts of the first echelon.

In view of the considerable inertia of the examined systems, significant changes in trends of their development cannot be realized instantaneously. Experience indicates that a large portion of scientific and technological data can be extrapolated within the range of the next 12-15 years with a permissible expectation of error of $\pm 15\%$.

Figure 24 shows an example of extrapolation of trends in the change of certain essential characteristics in electronic computer technology [95].

The forecast of the GDR scientist H. Fröhaut [96] can serve as an example of a forecast made by the method of extrapolating scientific

and technological data but by differing procedure. On the basis of the "Curve of the historical development of ranges of mastered waves" which he developed (Fig. 25), he asserted in 1957 that in the period 1965-1970 we should expect "mastery by means of electronic equipment of the region of continuously and connectedly oscillating light waves, their reproduction and amplification." Subsequently the forecaster specified his presentations on the scientific and technological means of penetrating into the indicated region. All of these were subsequently well confirmed by the experience of the creation of quantum generators.

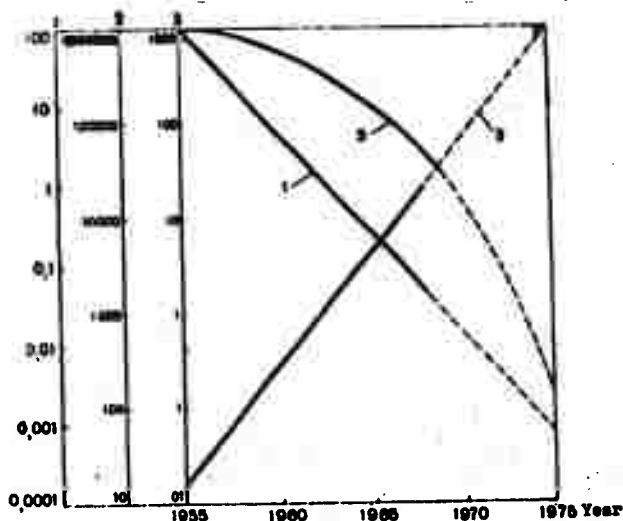


Fig. 24. Extrapolation of the change in characteristics of electronic computers. 1 - Cost (dollars per 10^6 op/s); 2 - operating speed ($1 \cdot 10^6$ op/s); 3 - volume (cubic feet).

Interest has existed for a long time in the analysis and extrapolation of trends of change in such characteristics of technical equipment functions as efficiency, carrying capacity per unit power, specific functioning energy capacity, etc. As an example of successful technical forecasting of this type we can cite the 1965 prediction of a reduction in specific (per one component) cost S_y of

integrated circuits of electronic equipment as a function of the quantity of elements included in them, n_s (Fig. 26). By 1970 the optimum size of n_s had increased by 20 times and the minimum value of S_y had increased by 10 times - the prospects were fully confirmed by world practice [93].

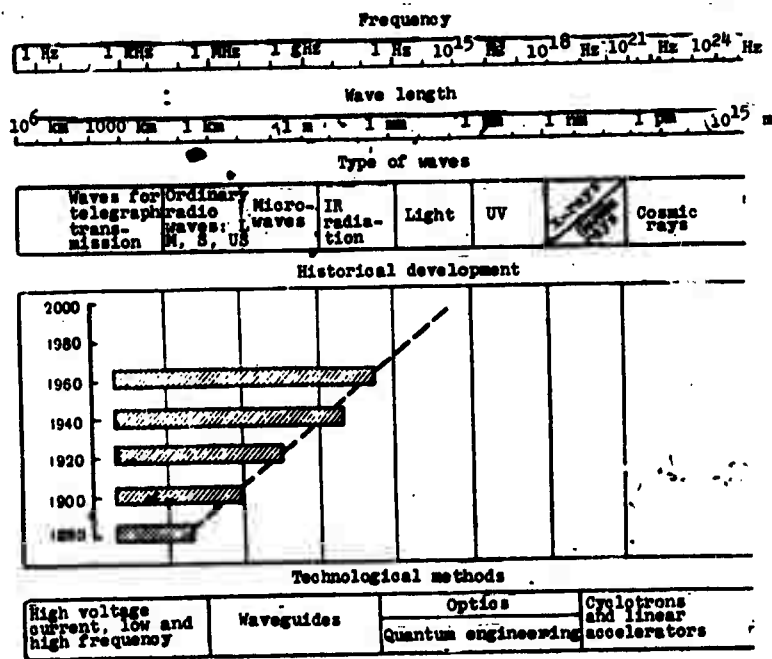


Fig. 25. Extrapolation of trends in the expansion of the range of mastered waves.

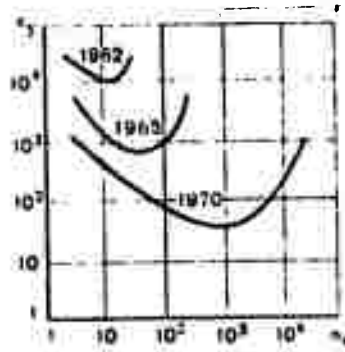


Fig. 26. Forecast of change in specific cost of integrated circuits of electronic equipment.

Forecasters use various methods to increase the accuracy of extrapolation. One of these, for example, consists in correcting the extrapolated portion of the total curve of development (trend) with consideration taken of actual experience in the development of an analog - areas of research or a technical object whose development is advanced over that of the predicted object. For example, on the basis of the fact that the development of civil aviation in the United States remains 5-7 years behind military aviation with respect to technical indices, American forecasters develop the assignment of designing a civil transport aircraft for the decade of the 90's. Trends in flight and technical characteristics extrapolated to 12-15 years were corrected in the middle segment according to data of the analog [87].

Another method consists in the simultaneous use of statistical and information data. We shall illustrate this with a generalized example of analysis of trends and forecasts of growth of a certain essential parameter τ (Fig. 27). Objects created in the i -th year in different countries had parameters τ_i varying within the limits Δc . Subsequent experience of the development of the object in each year multiplied the variety of achieved values of the parameter (different values have different designations on the figure).

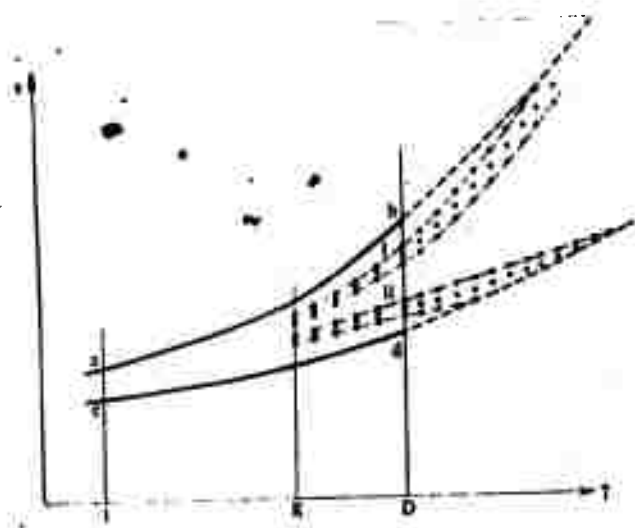


Fig. 27. Extrapolation of envelope curves of data on the world level of homogeneous technological parameters.

After all values with respect to the state in a year have been plotted on the diagram, it is possible to construct envelope curves of this array of data. The bands which they delimit represent in essence the world level of the parameter τ with its upper boundary ab and lower boundary cd. Within this band it is possible to single out two totalities of data, I and II, relating to the experience of creating analogous objects in different countries.

We can proceed further as follows. Envelope curves are extrapolated according to common rules. In this area of future world level we plot data taken from the characteristics of real objects in various stages of research, development, and design in a given country. It may be found that despite the apparent favorable situation (improvements of parameter τ provided in the designs), objects created according to these designs will form actually the lower boundary of the world technical level (case II). Naturally, case I is more favorable.

To the above we should once more add that no matter how important any one parameter τ may be, it never in itself permits evaluation of the object as a whole. As a rule, such analysis must be carried out with respect to the entire system of essential parameters of any object.

In the field of development of the organizational system of science there is usually special interest in extrapolation of mathematically described trends of the growth in the number and structure of scientific cadres. A. A. Zvorykin, L. V. Zarzhitskaya, and B. I. Spasskiy used this method to obtain the following calculated values of the number of scientific personnel with respect to our country (Table 11) [97].

A completed check of this procedure ("forecast" from 1950 to 1965) gave results which are sufficiently close to the real values.

Table 11.

Structural subdivision	1970	1980	Remarks
			In 1965
Specific fraction of scientists in the total number of the working population, %.....	4.83	6.12	2.87
Specific fraction of professional groups among scientists, %			
in the technical sciences.....	47.7	49.8	44.0
in physics and mathematics.....	10.4	11.0	9.6
in economic sciences.....	4.5	4.5	4.5
in the historical and philosophical sciences....	3.3	2.7	4.3

The extrapolation method was also used to forecast the growth in the volume of scientific and technological information, the magnitude of equipment available to science, and other questions. We will note that the specific evaluations of logical limits of growth or of one or another characteristic obtained in this case, and also the values of the breaks between mutually conditioning indices (see the extrapolation of U.S. requirements for scientists and the expectation of their number - Fig. 28) can serve as the basis for making important decisions with respect to future scientific policy [98]. One such decision is the predicted requirement for advance in the rates of growth of productivity of the labor of personnel occupied in scientific research as compared with the growth rates of the number of these personnel (Fig. 29).

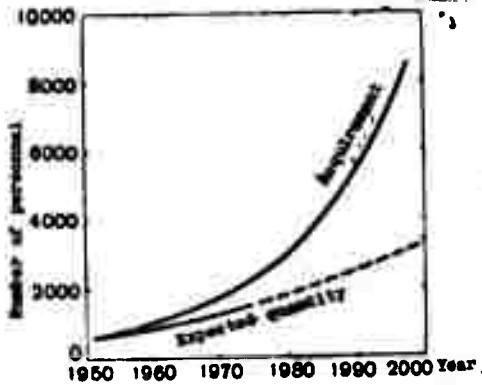


Fig. 28. Extrapolated break between the U.S. requirement for scientists and their expected number.

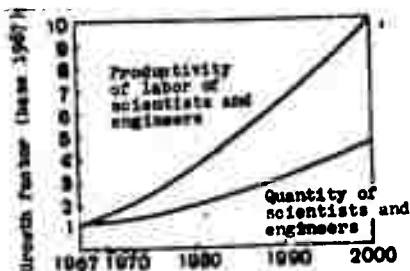


Fig. 29. Predicted requirement for lead in growth rates of productivity of the labor of personnel working in scientific research

Of particular interest in connection with this typical problem from the study of science are efforts to extrapolate data on the fruitfulness of the functioning of science. Students of science have collected and analyzed data on the rates of growth of new scientific data in different branches of science, conducting comparison of national statistics of scientific discoveries, inventions, etc. At present efforts are being made to study the correlation of data of this type with trends in the growth of capital investment in different branches of science and with the dimensions of applied research efforts [99].

Significant interest can be found in forecasts which extrapolate the ratio of the structural elements in science and technology and organizational and scientific systems: the structure of technical decisions of the transport area, the characteristics of the machine tool inventory, the ratio of research efforts in fundamental and applied sciences, etc. At present efforts to trace trends and to extrapolate the complex of quantitative and qualitative characteristics of the level of complexity of scientific and technological systems are also quite urgent.

If we regard extrapolation not as an end in itself, but as the beginning of analysis of trends and forecasting, we should recognize that the possibilities in methods of this type are very numerous and the practice of such forecasting is very broad, although in the majority of cases it is connected with forecasts of the first echelon. For prediction of more remote accomplishments of scientific and

technological progress, this approach must, as a rule, be supplemented with deeper penetration into the logic of scientific and technological development and the future capabilities of the fundamental natural sciences.

2. Methods of expert evaluations

The process of scientific creativity assumes the mandatory presence, at least, in leading scientists in each particular area of science of hypothetical presentations on the methods of resolving existing contradictions of the process, *a priori* evaluations of the significance of various decisions in science, and intuitive guesses on alternative and possible variants of development. In point of fact, an *expert* in the interpretation of this word applied in the study of science is actually a specialist who is developing such presentations and who is guided by them in the process of his scientific activity. Truly the aphorism which is popular among forecasters is not far from the truth: "an expert is a specialist who has already made a lot of errors." The curious psychological observation made by A. Clark (the so-called "Clark's Law") is adequately substantiated: when a competent but elderly scientist asserts "this is impossible," he is almost always right; when the same man gives the careful evaluation "this is impractical," there is adequate basis to hope that he is mistaken [100]. It is also noted that forecasts over very short periods (up to 5 years) frequently prove to be excessively optimistic, while those covering 20 years and more are often too timid [91].

Very widely used methods of forecasting are connected with the collection and systematization of different types of expert evaluations. In the eyes of the forecaster the conviction that if the reasoned judgements of a representative group of experts are the answer to real social, economic, or intrascience requirements, then the thoughts and assumptions contained in them are right for realization, gives force to the forecast.

In the ordinary case of qualitative analysis of *a priori* information of such a type, the period of accomplishment of the forecast

events is moved into the future by the expert according to the degree of his intuitive ideas on the complexity which he foresees at the present in the realization of the predicted assumptions. This relates completely, for example, to individual expert evaluations of the interview type.

In individual analytical expert evaluations this deficiency is partially overcome by providing the expert with the most complete possible information on the experience of development and various interconnections of the object of the forecast. The best known of the methods of this group is the so-called morphological method. Its author, the Swedish astronomer Fritz Zwicky, places in the forefront during forecasting the requirement of completeness of calculation of all known capabilities and properties of the given object. In essence the morphological method represents the business of "an ordered view of the thing" [101]. Its goal is to give a systematic survey and analysis of a given multilevel problem and thus to facilitate more successful use of the individual intuition of the expert.

One of the radical methods for increasing the accuracy and depth of forecasts which are based on methods of expert evaluation is to draw upon the expertise of a collective of competent specialists. For a long time and in many places this method was widely used in the form of the "commission method." It should be noted that the major portion of forecasts made earlier and used during prospective planning were obtained by precisely this method. In great part its success depends on the selection of the composition of the appropriate commission and the level of organization of its work. However, in any case this method entails two well-known deficiencies. Not all the experts are involved in an equally active process of creative thought. The evaluations and judgements of experts are usually influenced by factors which cannot be included among the number of scientific arguments: the authority and standing of colleagues who made judgements earlier; inertia inherent to the human during public rejection of his opinion; the emotional flavors of the assertions of an opponent, etc.

One of the efforts to overcome these deficiencies is represented in a special method of organizing the creative work of a collective of experts; in the USSR this approach is called the method of the related [referred] evaluation [102] or, in English terminology the "brainstorming" method [103]. The essence of the discussion procedure used here consists in the fact that the periods of free creative generation of ideas, proposals, and hypotheses are cleanly separated from the stage of critical evaluation of the obtained information, while the evaluation stage itself is carried out in such a form that it does not bind but rather stimulates further creative discussion of the problems.

Yet another of the recent efforts to resolve this same problem is the procedure adopted in the so-called Delphi* method for collecting and analyzing prediction information. Forecasting accomplished by this method by the "RAND" firm in 1962-1964 related to six broad regions: scientific discoveries, population growth, automation, mastery of space, the possible occurrence and the prevention of war, and future systems of armaments [104]. Representative groups of experts were assembled in accordance with a program of this type. The collecting of information consisted in successive questioning in depth of the opinions of 82 experts, who were sent four questionnaires at intervals of about two months**.

In the first round a list was formulated of the discoveries and inventions which the experts regarded as necessary and attainable in the course of the next 50 years (this was the МП stage). The second round saw accomplishment of evaluation of the probability of accomplishment and the expected waiting periods of these events: according to a specially stipulated procedure the most optimistic and the most pessimistic evaluations were excluded, and the greatest coincidence of opinion was determined for the remainder (stage ПП).

*It received its name from the Delphic oracle, which according to legend expressed independent points of view.

**Here we will examine only the first subject group of forecasts - scientific achievements.

In the third round the experts were given the analysis of the results of the preceding work. They were given lists of the completely matching opinions and also lists of incompletely matching evaluations on the problems which nonetheless serve for further discussion. Their judgements were requested on the possible reasons for the divergence of opinions, including those which depended on incomplete formulation of the problems, procedures, etc. In the fourth round they carried out a final correction of the collective expert evaluations. As a result there were obtained not the distribution of probabilities of appearance of a number of events, but statistically processed distributions of individual evaluations of experts with respect to the time of possible solution of one or another scientific problem. This significant circumstance must be kept in mind during critical analysis of future science as forecast by the Delphi method. A generalization of the results of this forecast is presented on Fig. 30, where the distributions of evaluations are plotted on the finally matched list of forecast events.

The experience accumulated by contemporary forecasting with different types of procedures of expert evaluations makes it possible to assert that the most important problems of collective expertise include the determination of the degree of matching of opinions of the experts on specific prospects of development formulated earlier by individual specialists (objectivizing the judgements), and evaluation of certain aspects of development which cannot be obtained by present methods (for example, by analytical calculation, experiment, etc.).

In order to achieve goals of this type, the process of collective expertise must be characterized by the following facts:

mutual independence of the judgements of the experts is ensured;

the evaluations, as a rule, are converted into quantitative form;

the expert indicates the structure of the arguments which served as the basis for one or another evaluation;

the expert indicates the degree of his familiarity with the field with which the particular evaluation is related.

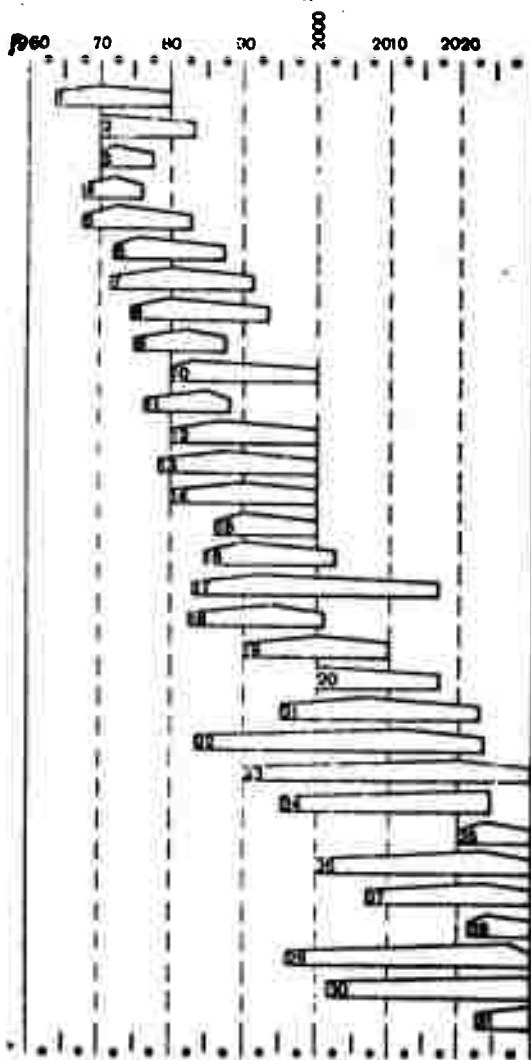


Fig. 30. Forecast of expected events of scientific and technological progress (summary table). 1 - Economically feasible distillation of water; 2 - effective and inexpensive control of the birth rate; 3 - new synthetic materials for superlight structures; 4 - machine translation from language to language; 5 - organ transplants and prosthetics; 6 - reliable weather forecasting; 7 - the creation of a unified information center; 8 - reformation of theoretical physics (liquidation of present contradictions); 9 - implanting of artificial organs made of plastics and electronic components; 10 - distribution of nonnarcotic preparations to change the psychological peculiarities of people; 11 - lasers in the x-ray and γ -range of the electromagnetic spectrum; 12 - controlled thermonuclear power; 13 - artificial creation of primitive forms of life (self-dividing molecules); 14 - economically feasible development of living areas on the ocean floor; 15 - limited and economically feasible control of the weather in limited areas; 16 - industrial production of synthetic protein (food products); 17 - manifold expansion of the area of treating mental illnesses; 18 - universal immunisation against bacterial and virus diseases; 19 - chemical control of birth defects (gene modification); 20 - use of the ocean as

the source of 20% of world reserves of food products; 21 - biochemical preparations which stimulate regeneration; 22 - medicines which increase mental development; 23 - direct interaction between the human brain and electronic computers; 24 - prolongation of human life by 50 years; 25 - the use of monkeys and dolphins for unskilled labor; 26 - two-way communication with extraterrestrial civilizations; 27 - industrial production of chemical elements from subatomic components; 28 - control of the force of gravity by changing the gravitational field; 29 - education by means of direct recording of information in the brain; 30 - prolonged lethargy [suspended animation] for "traveling in time"; 31 - the utilization of telepathy and Esperanto for communications.

The success of collective expertise is facilitated, mainly by the interested attitude of the experts - as, for example, when they place themselves in the position of direct participants in events, who can be responsible for their realization of the advanced positions, rather than mere disinterested observers.*

Our presentations** on the procedure for collecting and processing the data of expert evaluations can be outlined in the form of a few working stages.

1. Before the beginning of forecasting research and in accordance with its assignments, the so called "goal - means" matrix is developed; the cells of this matrix should be filled with information obtained as the result of analysis of all data collected by forecasters (including that obtained from the experts). Here, in cooperation with specialists, several of the most important goals and subgoals (paths) of solving the selected problem are determined in the course of preliminary analysis. The approaches for solution should be formulated in such a manner that as a set they can lead to solution of the problem and do not overlap one another. The paths for solution (subgoals) form the columns of the matrix.

Under the term means of achievement of goals we understand the directions of research and development whose results can serve for achievement of the goal. They are so grouped and formulated that all basic directions of research and development whose results might serve to achieve the goals will be taken into account. Besides this, they should not overlap one another. The means of achieving the goals form the rows of the matrix.

The typical form of such a matrix is shown on Fig. 31. In the particular case of forecasting the development of computer technology the columns and rows can be expressed in the following formulations.

*The idea of ensuring a responsible attitude of the experts was put forward and formulated by Academician V. M. Glushkov.

**Together with L. P. Smirnov and Yu. V. Yershov.

The general goal: achievement (within limits) of a situation when everyone in all spheres of activity solves problems with the aid of electronic computers in a resonable time, in an economic manner, obtaining results in a form convenient for use. Subgoal A: solution of the problem of communication of man with computer. Subgoal B: increasing the "intellect" of the electronic computer. Subgoal C: developing effective productivity of individual electronic computers and total productivity of the computer inventory of the nation. Group of means a: improving the elementary and technological base. Group of means b: improving auxiliary devices and communications techniques. Group of means c: development of methods of data processing (mathematized methods of solving problems). Group of means d: improvement of software. Group of means e: improvement of electronic computer structure. Group of means f: improving the organization of use of electronic computers. Group of means g: improvement in methods of designing electronic computers.

Goal Means		General goal			
		Path A (subgoal)	Path B (subgoal)	Path C (subgoal)	Path D (subgoal)
Means of achieving the goal	Group of means a				
	Group of means b				
	Group of means c				
	Group of means d				
	Group of means e				

Fig. 31. "Goal - means" matrix.

The formulation examples which are given do not, naturally, pretend to completeness or an exhaustive character. They are calculated here only in order to give a concrete definition of the idea of the "goal -- means" matrix. The advisability of using it lies in the fact that the main work of the collective of forecasters is further reduced to filling in the matrix with contextual and argumentative information relating to МП, ПП, and ОП.

2. The following stage of collective evaluation consists in development of "Tables of expert evaluation" with questions. These tables should ensure that the following are obtained from the expert:

quantitatively defined responses to the stated questions;

formalized information on the nature of sources of argumentation and also on the degree of influence of each of them on the expert's response;

quantitatively defined evaluation of his familiarity with the field to which the stated question relates.

To fulfill the first condition the problems being posed to the experts were classified as follows:

a) evaluation of the relative importance of the development of different directions of research and developments. The expert is requested to give an evaluation (in points on a 100-point scale) of the relative importance of the development of different directions of research and development for the solution of a certain problem;

b) evaluation of the time for accomplishment of a certain event. The expert is asked, for example, to place a mark on a time scale in accordance with his opinion of the time when a certain event will be accomplished. Question: when, in your opinion, will event A be achieved? Answer (see Fig. 32): the event will be accomplished in the USSR in the 1980 to 1985 period, and in the USA from 1975 to 1978;

c) evaluation of the "specific weight" of different types of problems, types of technical decisions, etc. The expert is asked to

make a mark on a percent scale (from 0 to 100) in accordance with his opinion of the "specific weight" of a certain type of problem, items, etc. in the time periods subject to forecast;

d) adherence to one of the alternative judgements. The expert is asked to mark that judgement with respect to the development of a given branch of technology in the course of the forecast period which most corresponds to his point of view.

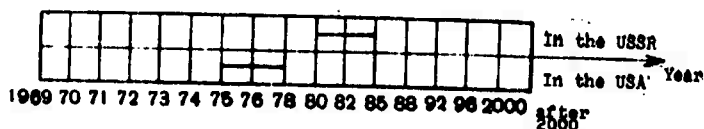


Fig. 32. Scale of the range of events on the time axis.

To fulfill the second condition - obtaining formalized information on the nature of sources of argumentation and also on the degree of their influence on each group of the expert's responses - the expert is asked to mark in the table (Table 12) the sources of argumentation serving as the basis for his response. The mark is made in one of three columns, depending on the degree of influence (high, moderate, low) of each source on the opinion of the expert.

Table 12.

Source of argumentation	Degree of influence on the opinion of the expert		
	high	moderate	low
Completed theoretical analysis.....	X		
Industrial experience.....	X		
Generalization of work of Soviet authors..		X	
Generalization of the work of foreign authors.....			X
Personal familiarity with the state of the art abroad.....			X
Intuition.....		X	

In the above case the table filled out by an expert indicates that his opinion on the question was developed to a high degree by his previous theoretical analysis and personal industrial experiments; it was influenced to a moderate degree by generalization of the works of Soviet authors and also by personal intuition, and to a small degree by generalization of the work of foreign authors and by his personal familiarity with the state of the art abroad. All of these evaluations are converted by the forecasters into a quantitative form by means of tables of weighted coefficients.

To fulfill the third condition — obtaining a quantitatively defined evaluation of the degree of familiarity with the field to which the stated question relates — the expert is requested to make a mark on a scale (from 0 to 10), where the maximum evaluation (10) corresponds to familiarity with the problems of a certain question at the level of authorship (co-authorship) in the development of certain solutions of the discussed problem, while the minimum evaluation (0) corresponds to the most general familiarity with the appropriate problem.

3. Organizing and carrying out interrogation of the experts. On this stage it is extremely important to guarantee that the individual questions are understood by the experts in the same way and also to create conditions for free and independent expression of judgements.

All responses received from the experts are processed and studied by forecasters in two aspects: 1) analysis of the content of the problems and of the approaches to their solution, and 2) conversion into the form of quantitative evaluations. These and other data serve as the initial elements for the synthesis of forecast hypotheses and variants of development. In any case, forecasters who are using expert evaluations must be warned against two extremes which constantly threaten them: excessive faith in the individual judgements of authorities, on the one hand, and blind following of a depersonalized statistical majority, on the other. Attentive examination and consideration of the structure of arguments of the experts, differentiation of approaches in accordance with the specific

features of the object of the forecast - these are essential criteria of a truly scientific forecast. In a research forecast on fundamental sciences the greatest weight will, probably, be vested in individual judgements of the experts; in program forecasting of applied research and development special attention is paid to the predominant views of specialists, and in an organizational forecast the forecaster must strive to the maximum to use the capabilities of direct calculation of resources, requirements, and prospects.

The procedure for statistical processing of the materials of an expert evaluation depend on the nature of the questions posed to the experts. As an example, a procedure for processing expert data on two types of questions is outlined below.

Evaluation of the relative importance of different directions of research and development. The specific features of processing materials of an expert evaluation on problems of this type are connected with the selection of the indices of importance. The following indices of importance can be introduced.

Average statistical value of the quantity of an evaluation of a certain direction of research (in points):

$$M_j = \frac{\sum_{i=1}^{m_j} a_{ij}}{m_j}, \quad (1)$$

where M_j is the mean statistical value of the quantity of the evaluation of the j -th direction of research; m_j is the number of experts who evaluated the j -th direction of research; a_{ij} is the evaluation (in points) of the j -th direction of research by the i -th expert.

The coefficient of "specific weight" of a given direction is

$$k_{yj} = \frac{\sum_{i=1}^{m_j} a_{ij}}{\sum_{j=1}^n \sum_{i=1}^{m_j} a_{ij}}, \quad (2)$$

where n is the number of directions of research; k_{yj} is the coefficient

of the specific weight of the j -th direction of research, characterizing the fraction of the total of points received by the j -th direction of research in the total of points obtained by all directions; $k_{a.s.j}$ is the coefficient of the "activity" ["enthusiasm"] of the experts for the j -th direction of research:

$$k_{a.s.j} = \frac{m}{n}, \quad (3)$$

where m is the total number of experts taking part in the expert evaluation and n represents the number of directions of research.

The frequency of the highest (maximum possible) evaluations is

$$k_{100j} = \frac{m_{100j}}{m_j}, \quad (4)$$

where k_{100j} is the frequency of the maximum possible evaluations obtained by the j -th direction of research; m_{100j} is the number of maximum possible evaluations (100 points) obtained by the j -th direction of research.

Yet another index of importance — the sum of the ranks S_{Rj} — is determined in accordance with the methods of rank correlation [105, 106] by two groups of operations.

1. Ranking with respect to diminishing evaluations given by each expert on each direction of research. For this purpose numbers of a natural series are ascribed to the evaluations given by the i -th expert to j directions of research: number 1 — maximum evaluation, and number n — minimum. If all evaluations are different, the corresponding numbers of the natural series are ranks of evaluations by the i -th expert of these directions of research.

If some of the evaluations given by a certain expert are identical, an identical rank is ascribed to them equal to the arithmetic mean. The number of experts evaluating at least one direction of research will be designated as m_1 .

2. Determination of the sum of ranks assigned by m_1 experts to the j -th direction of research:

$$S_{Rj} = \sum_{i=1}^{m_1} R_{ij}, \quad (5)$$

where R_{ij} is the rank assigned by the i -th expert to the j -th direction of research.

It is obvious that during comparison of the importance of different directions of research in terms of S_R the direction which is characterized by the least value of S_R should be considered to be the most important.

Determination of the degree of matching of opinions of the experts with regard to the relative importance of a certain direction of research is extremely important. It is characterized [107] by the variation coefficient, which is the relative mean square deviation:

$$v_j = \frac{\sigma_j}{M_j}, \quad (6)$$

where v_j is the variation coefficient for the j -th direction of research; σ_j is the mean square deviation of the evaluations (in points) given to the j -th direction of research; M_j is the mean statistical magnitude of the evaluation (in points) of the j -th direction of research.

The mean square deviation σ is determined according to the formula

$$\sigma_j = \sqrt{\sigma_j^2}, \quad (7)$$

where σ_j^2 is the scatter of evaluations assigned to the j -th direction of research:

$$\sigma_j^2 = \frac{\sum_{i=1}^{m_j} (R_{ij} - M_j)^2}{m_j}. \quad (8)$$

The degree of matching of evaluations given to all directions of research by the collective of experts is characterized by the

concordance coefficient W , which is defined [105] for each table of evaluation of importance by the formula

$$W = \frac{12 \sum_{j=1}^m d_j^2}{m_1^2(n^2 - n) - m_1 \sum_{i=1}^{m-1} r_i^2}, \quad (9)$$

where d_j is the deviation of the sum of ranks obtained by the j -th direction of research from the arithmetic mean of the sums of ranks obtained by all directions of research; d_j is determined by the formula

$$d_j = S_{Rj} - M[S_R], \quad (10)$$

in which S_{Rj} is the sum of ranks assigned by m_1 experts to the j -th direction of research and $M[S_R]$ is the arithmetic mean of the sum of ranks obtained by all directions of research. It is defined as

$$M[S_R] = \frac{\sum_{j=1}^m S_{Rj}}{m}; \quad (11)$$

T_1^i is the index of connected (equal) ranks and depends on the quantity t of them designated by the i -th expert:

$$T_1^i = \sum_t (t^3 - t). \quad (12)$$

If all n evaluations (ranks expressed by the i -th expert) are different, then $T_1^i = 0$. If some among them are identical, T_1^i is determined according to formula (12).

The concordance coefficient W can take the values $0 \leq W \leq 1$. With complete matching of the opinions of the experts $W = 1$. The change in W from 0 to 1 corresponds to an increasing degree of matching of the opinions of the experts.

During determination of the concordance coefficient the problem of the level of significance, i.e., the determination of the probability that the agreement of opinions of experts as characterized by the defined concordance coefficient is a random coincidence, is a very important matter.

We shall employ the so-called Pearson criterion χ_R^2 for determination of the significance level.

We will calculate the quantity χ_R^2 by the formula

$$\chi_R^2 = \frac{\sum_{i=1}^n x_i^2}{m_{12}(n+1) - \frac{1}{n-1} \sum_{i=1}^n x_i} \quad (13)$$

We will determine the number of "degrees of freedom" as

$$\nu = n - 1. \quad (14)$$

Then we use the table of values of "chi-square" to find for a given number of degrees of freedom ν the tabular value which is closest to the value of χ_R^2 determined according to formula (13). We use the same table to determine the level of significance for the found tabular value.

An important element of the procedure of processing the data of an expert evaluation is the determination of the group of experts within which matching of opinions is high, and also finding experts who have unique points of view which differ from the opinion of the majority. On the subsequent stages of expertise this makes it possible to formulate counterarguments against the most widely held directions in order either to strengthen the position of the majority or to carry out a number of additional studies to check sharply differing evaluations of individual experts.

A low value of the concordance coefficient indicates weak matching of opinions of the experts. Usually this is observed in those cases when a certain commonality of opinions has not been developed within a given group of experts or when opinion within the group is divided. This problem is studied in the process of forecasting both on the contextual level and by means of diagrams of paired correlation.

Evaluation of the time of accomplishing an event. The arrangement of evaluations on a time scale is characteristic of problems of this

type. During statistical treatment of such materials it is advisable to use such methods as determining the upper and lower quartiles and the median of distribution of evaluations. These parameters characterize the investigated totality of initial data with adequate completeness.

The upper and lower quartiles and the median are determined as follows. First of all the evaluations are ordered along the time axis. The middle term of the evaluations arranged along the time axis forms the median. The median possesses this property: the number of evaluations (arranged along the time axis) which indicate earlier dates and those which indicate later dates are equal in number. Then the values of the upper and lower quartiles of the ordered totality of evaluations are determined. These values are selected in such a manner that 25% of all evaluations will be earliest and 25% will be latest. The quartiles and the median break up the totality of evaluations into four groups which are equal in number.

The value of the median can be interpreted as the index of the generalized opinion of the experts on the time of achievement of a certain event. The values of the two central quartiles, and also those of the earliest and latest evaluations, characterized the degree of matching of opinions of the experts concerning the time of accomplishment of the event.

Some results of processing the data from a collective expert evaluation are given below*. These results represent an insignificant part of the conclusions obtained in the expertise process and are presented in the given case only as an illustration of certain possibilities of the outlined procedure.

Table 13 summarizes the results of a collective expert evaluation of the relative importance of the development of different directions

*The work was accomplished according to a directive of the Goskomitet of the Council of Ministers, USSR, on science and technology. A broad circle of specialists from various organizations took part in it. A total of 43 experts participated in the experimental check of the procedure.

of research and development for achieving the subgoal of facilitating the man-computer interface. The table shows the ranks of significance described above as evaluated by various indices. According to this table the coefficient of concordance $W = 0.411$ for a significance level of 0.001.

For the overall purpose and for all three of its subgoals (including that examined in Table 13) the experts recognize as one of the most important areas of research the improvement of software. The improvement of peripheral gear and communications techniques, and also the development of formal languages, were evaluated as most important features for solving the problem of facilitating the human/computer interface. Naturally, the relative importance of different areas, studies, and developments varies depending upon the specific subgoal. Improvement in the structure of electronic computers was recognized as one of the most important directions for improving the "intellect" and productivity of computers, while improving the organization of computer use is recognized as having high importance for increasing the total productivity of the nation's computer inventory. The experts consider the improvement in the elementary and technological base as being most important for improving the productivity of an individual electronic computer.

The distribution of opinions of the experts relative to the time of accomplishing one specific event in improving the construction of electronic computers - the introduction of multifunctional element circuits which can be adjusted according to a program - is shown on Fig. 33. According to this generalized evaluation, such an event can be expected in the U.S. in the 1975-1976 period and in the USSR in 1976-1978 (in each case the medians are indicated by the shaded strip of the time interval). When including such evaluations into a synthetic forecast information set it is appropriate to turn attention to the lengthiness of the range of evaluations, in particular with respect to the two central quartiles, reflecting the greatest coincidence of opinions of half of the experts (in the considered example the scatter of such evaluations with respect to the USSR comprises 3 years and that with regard to the USA is 6 years).

Table 13.

Direction of scientific and technological research and development	Evaluation of the relative importance of development of directions of research and development													
	Without consideration of the level of competence of the experts													
	M		Ky		K _{int}		SR		M					
	abs. val.	rank	abs. val.	rank	abs. val.	rank	abs. val.	rank	abs. val.	rank				
Improvement of the element-technological base.....	37,0	8	0,074	8	0,077	7	271,0	8	29,00	8	0,079	8	39	0,907
Improvement of peripheral devices and communications technology.....	91,3	1	0,183	1	0,714	1	91,5	1	65,10	1	0,111	5	42	0,987
Development of data processing methods.....	60,5	5	0,122	5	0,146	5	211,0	5	43,80	5	0,129	4	41	0,954
Improvement of software.....	78,4	2	0,157	2	0,342	2	136,5	2	55,90	2	0,164	1	41	0,954
Improvement of computer structures.....	49,9	7	0,100	6	0,154	4	238,5	7	38,10	7	1,103	7	39	0,907
Improvement in the organization of computer use.....	65,6	4	0,131	4	0,126	6	160,0	4	48,60	4	0,133	3	40	0,930
Development of computer design methods.....	24,4	9	0,049	9	0,028	8	334,5	9	17,90	9	0,049	9	36	0,837
Creation of formal languages for individual scientific areas.....	70,4	3	0,141	3	0,214	3	178,0	3	51,80	3	0,142	2	42	0,977
Development of human factors engineering investigations of the "man/machine" system.....	53,3	6	0,107	7	0,026	9	237,5	6	38,20	6	0,104	6	39	0,907

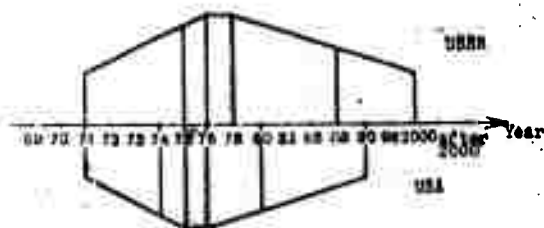


Fig. 33. Evaluation of the time of introduction of multifunctional element circuits adjustable according to a program into lot-produced electronic computer structures.

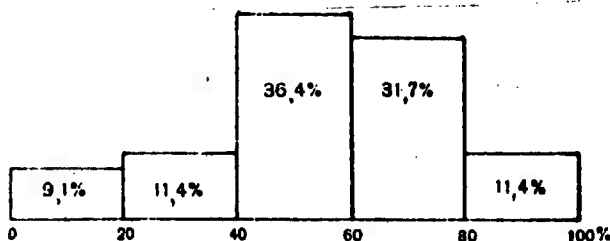


Fig. 34. Evaluation of the optimum specific fraction of multiprogram electronic computers in the future computer inventory of the nation.

Figure 34 gives a clear presentation of the distribution of expert opinions with regard to the optimum specific weight of multiprogram machines in the country's electronic computer inventory in the next 10-15 years. The majority of experts (~70%) consider that this index falls within the limits of 40 to 80%. The generalized evaluation of the experts (statistical average value of evaluations) amounts to this: the optimum specific fraction of multiprogram electronic computers will comprise a quantity on the order of 55% of the total number of operating machines.

The experts were also requested to join in one of the judgements on the problem of improving the organization of electronic computer utilization. Results of processing the opinion showed the following: the majority of experts (~80%) consider that in the case of rational organization of electronic computer utilization it is advisable to attempt to

reach a situation in which each user has "his own" computer only for solution of simple monotypic problems which occur in large quantities, while when solution of complex problems is necessary centralized service should be provided or access to large processors by means of panels and communication lines should be made available. Only about 3% of the experts join in the opinion that each user should have "his own" electronic computer for solution of all problems.

The results of an experimental check of the outlined procedure for collective expert evaluation made it possible to conclude that it is suitable for purposes of scientific and technological forecasting. At the present time the procedure is being improved in the direction of perfecting methods of dividing experts into groups within which the matching of opinions is high, and also methods for bringing out and considering unique (although few in number) opinions of experts on stated questions [109].

One very promising idea for the future development of methods of expert evaluation (V. M. Glushkov) consists in the following: clarifying and formulating conditions for achieving each of the levels of progress in the forecast region in the process of goal-directed and multistage interrogation of experts. The sequence of actions being undertaken here is typical for program forecasting — the problem is "scanned" from the future to the present for the purpose of establishing intermediate key events and fixing the cause-effect relations between them: goal A is formulated; the experts advance the realization of events a and b as conditions of its achievement (here and below the expected significance and probability of accomplishing the events is evaluated); for the achievement of events a and b the experts (their professional composition can vary on each step of the development) designate new conditions (x, y, z and α , β , γ , etc.) right up to occurrence of events which are today actually included in the plan of scientific research and development.

The hypothetical nets of events constructed in this way are characterized both by the presence of critical and subcritical paths and by the presence in them of "dependent" branches of events for which the positions of contemporary ideas do not permit the formulation of realization conditions which merit confidence.

The content of these cases is the object of special study. Besides this, the nets are analyzed mathematically by methods developed for evaluation and forecasting of planning and control nets (PCN). The results of the work are used to forecast the most urgent programs of future research and development.

Special attention is paid to the "dependent" branches of events. With regard to certain of these which are capable of causing significant changes in the process of achieving the basic goal, the forecasters formulate argumentative proposals on the organization of special exploratory research. Others are studied in the course of subsequent forecasting work by means of all known methods, including informational (and in particular patent) analysis.

It is important to emphasize that this entire procedure is subject to algorithmization. The obtained nets of events with all evaluations and incompleting branches are stored in the memory of an electronic computer. Accomplishment of survey and analysis of the nets and the course of their realization by means of electronic computers is also provided. In the course of actual investigations and also on the basis of newly arriving scientific and technological information and expert evaluations it is possible to provide relatively objective and automatic reevaluation of earlier formulated hypotheses, right up to output of information on the necessity of returning to a previously rejected variant of development of the work.

Since the forecast information (in view of the conditions of the expertise method) included information on specialists trained under newly arising conditions to decide a certain problem and to give the most highly justified evaluation of the routes of its solution, the electronic computer can formulate preliminary assumptions on the composition of executive agents for a cycle of research or developments, which becomes particularly urgent under the influence of newly arising requirements and scientific and technological capabilities.

The method of forecasting problem research developed at the Institute of Cybernetics of the Georgian Academy of Sciences [110]

may prove useful for the realization of ideas of this type. The ideas of induced heuristic programming which are used here are assigned on the basis of a survey of a logically complete set of "object" signs by a group of experts with participation of a forecaster (chief) to stimulate psychologically the unique process of formulating paths for the development of problems and the advancing of hypotheses and considerations on the most promising successive actions of the researcher.

Realization of these possibilities as they unfold before the forecaster will, in essence, designate transition from methods of expert evaluation to methods of simulation of the predicted concepts.

3. Simulation methods

Forecasters rest very great hopes on solution of the problem of simulating essential processes and phenomena of scientific development. The study of science as a whole only approaches the development of the problem of simulating its specific objects of scientific study. Certain existing methods of forecasting using the simulation approach are more worthy of intensive attention. In this respect the group of methods of forecasting by historical analogy has the oldest traditions.

On the basis of study of the internal logic of the development of a specific scientific discipline the researcher constructs an historical logical model corresponding to it. Then the resolution of certain conflicts in situations possessing a commonality of properties with it is forecast in accordance with this model [111]. The popularity of logical specimen models designed by means of the method of historical analogy rests not only on traditions but also on the many acts of continuity in the development of scientific principles and ideas, well-known to historians of the natural sciences.

In this connection the judgement formed 35 years ago by S. I. Vavilov is of interest. He turned his attention to the "obvious and anything but trivial growth in natural sciences and technology and the hundreds of thousands of people creating the history of science on

the globe before our eyes. We cannot pass without turning attention to this tireless motion, this powerful phenomenon of nature, capable of changing the Earth no less radically than earthquakes and floods. As ever, to understand this process means in many respects to master and to learn to direct it where necessary. The history of science is a necessary and, if you please, even sufficient prerequisite for planning science. Therefore sooner or later the history of science must become a science. Up to this time, however, it remains in the cradle of personal characteristics and biographies, chronological dates, and in many cases very imperfect documentation" [112].

A consciousness of history in the approach to forecasting is a mandatory condition for the latter to be of a scientific nature. It is mandatory, but is by no means sufficient. During direct forecasting, the need for using historical experience (in particular, analogies) with extreme care is completely obvious — it is necessary to consider with special caution the specific features of the sciences to be forecast and to bear in mind requirements and capabilities of their development which are new in principle and which arise in the new historical situation; not infrequently they occur in remote fields of science, technology, and production. If the method of historical analogies were universal, as we are frequently inclined to regard it, scientific and technological policy would be formulated by historians and not by specialists who know contemporary experience best.

At the same time a very important factor in the forecasting and planning of new technology and of new scientific research work is the definite quantitative evaluation of the volume, completeness, and effectiveness of the utilization of accumulated experience, and specific trends toward absorption of new scientific results, including those obtained by the fundamental sciences, by a given branch of technology. The urgency of this problem arises from the sharply growing rates of obsolescence of technical equipment in the contemporary era.

The American project "Hindsight"* (1964-1966) [113, 114], specially oriented toward study of this problem, permitted a retrospective evaluation of the effectiveness of a complex of applied scientific research, specifically evaluating (in terms of time, money, achieved technical parameters) the characteristics of those new ideas which led to improvements in each of the investigated technical systems over the preceding systems.

The majority of these ideas fell outside the field of fundamental sciences and exploratory research. Out of 43 basic technological "events" which made possible, for example, the missile system "Bullpup," 23 were accomplished in a period of more than 12 years (maximum - 40 years), while 20 fell within this period (minimum 4 years). There was also obtained a specific value of the minimum required totality of innovations (in the given case the "critical mass" = 46% of the "events"), making it possible to achieve new properties on the basis of known ideas.

This type of specific analysis of the historical scientific and technological experience can place a number of essential "normative" data at the disposal of ON and ON.

In a number of cases direct long-term planning of scientific and technological development is preceded by logical simulation in complex form of the future scientific and technological policy, including the following: the formulated economic, political, and other goals of the given state, description of a number of scientific and technological possibilities for their achievement, the characteristics of resources and requirements which condition the advisability of making this or that government decision. In scientific forecasting such a descriptive document is called a "scenario of the future." Usually it must be developed after completion of a complex of operations with respect to quantitatively determined forecasting [115, 116].

*Hindsight (Eng.) - looking back.

A specifically important role in the entire outlined concept of forecasting is played by methods of data simulation. The characteristic properties of massive flows of scientific and technical information considered by us earlier (Chapter II) predetermine a number of possibilities for analyzing trends in the progress of science and technology with respect to "information signals" - by the change in the quantitative and structural parameters of these flows.

These ideas are outlined systematically in the collective works of Soviet scientists [12, 13, 117-120] dedicated to analysis of the laws of scientific and technological development and to forecasting it. Therefore we will limit ourselves here to the characteristics of the principal aspects of information methods of analysis and forecasting.

The interesting possibilities of understanding the technical ideas which have a tendency to alter the aspect of a given type of technology are opened by analysis from all sides of the array of claims of inventions - the earliest and most complete collection of documents reflecting the search for new technological solutions. As an example, Fig. 35 shows a diagram which we prepared together with L. P. Smirnov as the result of analysis of initial Soviet claims to inventions in mining technology.

Data on this type reflect a regular process influenced by practical experience, industrial requirements, and scientific research. In the considered case this is expressed in the redistribution of the interest of combine designers from the use of the principle of cutting action to the use of the more promising principles of fracturing the coal ("heavy chipping," planing, and their combination). It is appropriate to call attention to the fact that both here and in the example outlined earlier (Chapter II, Figs. 7 and 8) the thematic redistribution of efforts of creators of new technology was approximately 8-10 years in advance of the changes occurring in the subsequent, actually created technical equipment.

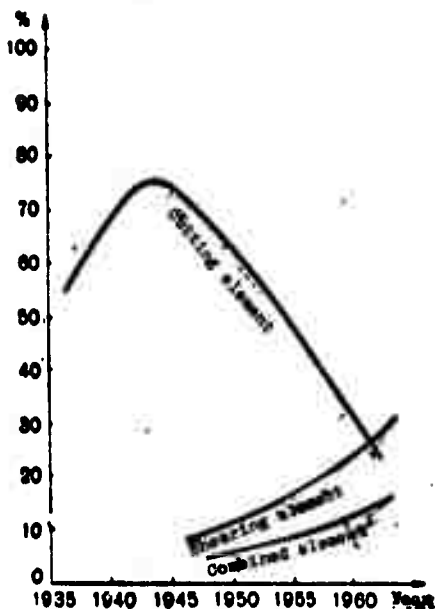


Fig. 35. Trends in the thematic redistribution of efforts of creators of new technology.

Active efforts are also known to develop methods of analyzing information signals found in flows of published patent documents concerning world technological experience. By coding the information contained in patents on a certain class of technical equipment it is possible to determine those elements and types of technical decisions for which the acceleration of the increment of new data (Y) essentially differs from the average values. B. N. Tardov proposes* that this be considered as signaling the fact that in 5-8 years a decision of this type will alter the corresponding characteristics of practically applicable technical equipment.

For example, here is how such characteristics calculated according to the world patent literature of recent years as relating to the design of aircraft would appear. While as a whole $Y = +11.0$ in this

*This problem is the subject of a series of articles by B. N. Tardov in the collections [119, 120, 126].

area, with respect to the problem of vertical takeoff $Y = +22.0$; as regards ideas for changing the direction of the jet flow $Y = +26.0$, and with respect to thrust reversal $Y = +23.0$, etc. The smallest values of this information flow are found with respect to such elements as a wing with a variable area, $Y = -22.0$, hermetic sealing $Y = -17.0$, annular and semiannular wings $Y = -15.0$, etc. [12, page 100].

Subsequently it is necessary to verify the forecast value of the engineering and technological conclusions ensuing from detailed analysis of patent data. The procedure for classification of the content of patents and evaluation of the nature of the data requires improvement with consideration of the principal differences existing in national patent systems and in the motivation for patenting new ideas, and with account taken of the influence of world market conditions on this process.

A developed concept of technical forecasting based on analysis of patent information was presented in the works of V. G. Gmoshinskiy [12, 119, 121], a specialist at the TsNIPI [Central Scientific Research Institute of Patent Information and Technical and Economic Research]. A special feature of this approach is the effort made during analysis of the dynamics of patenting to take into account qualitative characteristics of patents which determined their engineering, technological, and potential economic significance - to give them a generalized quantitative evaluation.

The developed procedure provides that the forecaster who is familiar with a specific area of technology will accomplish three successive stages of the work: a) evaluation of each of the totality of patents to be analyzed for so-called "completeness" (engineering and technological significance and economic promise); b) determination of the promise in different groups of technical decisions by comparing the summary indices of significance of the decisions which compete against each other (intended for solution of similar problems); c) evaluation of the level of patenting with respect to the subdivision of technical equipment (branch) as a whole and the formulation of general conclusions about development trends on this basis.

Table 14.

Characteristics and positions		Evaluation (points)	Evaluation with consideration of "weight" of characteristic
<i>Engineering and technological feature of the patent solution</i>			
Improvement of parts of existing structures or individual stages of operations.....		1	0.992
Improvement in units of existing structures and several stages of operations.....		2	1.984
Improvement in units of existing structures and stages of operations at a new level of mechanization, automation, and net control.....		3	2.976
A new solution having the sense of a basic patent (accompanied later by protective patents).....		4	3.968
A discovery which is new in principle, having the sense of a discovery in the given field.....		5	4.900
<i>Level of theoretical validity</i>			
Foundation for patent given on the level of empirical formulas and elemental hypotheses.....		1	0.984
Has in mind the simplest presentations on linear connection between stresses and strains.....		2	1.968
Considers plastic and low-plastic properties of the medium (soils, concrete in different stages of hardening).....		3	2.952
Considers creep of the medium (time factor).....		4	3.936
Considers contemporary theories of strength and susceptibility to destruction of materials on all stages of construction and use of foundations.....		5	4.920
<i>Service life of foundation structures</i>			
Operating methods and applicable materials ensure a service life of foundations up to 10 years (temporary structure).....		1	0.960

Table 14 (continued).

1			2	3
The same, from 10 to 40 years.....			2	1.920
The same, from 40 to 70 years.....			3	2.880
The same, from 70 to 100 years.....			4	3.840
Operating method and suitable materials do not limit the service life of foundations.....			5	4.800
<i>Guaranteeing industrial safety conditions in the course of construction</i>				
Patent decision does not satisfy industrial safety conditions.....			1	0.884
Industrial safety conditions are satisfied for individual units and production operations, but are not met for the construction and production cycle as a whole.....			2	1.768
Industrial safety conditions are ensured for units and the structure as a whole (or with regard to all technological operations).....			3	2.652
Noiseless work is guaranteed on all operations with industrial safety conditions being met for units and the structure as a whole.....			4	3.536
The operating method guarantees complete safety during all production operations, without exception, and has no damaging effects on neighboring structures (absence of shaking, waves, washouts, etc.).....			5	4.420
<i>Licensing and market factor</i>				
The patent has not been introduced into production and is not realized in the form of licenses.....			1	0.626
The patent is not used in production and is not realized in the form of licenses, but has favorable conditions for introduction (the solution recommends itself) and for the sale (purchase) of licenses.....			2	1.252
The patent has been used in production by the firm which is patenting the given solution.....			3	1.878
Licenses to the patent or sample specimens (for pile-driving equipment) have been acquired by a number of firms and corporations in the country where patented.....			4	2.504
Patent licenses have been acquired in a number of countries.....			5	3.130

Evaluations are carried out in dimensionless quantities (points). The criteria for designation of quantitative evaluations are summarized in special tables developed for each class of technical equipment. These tables contained five characteristics with five positions in each (10 × 10 tables are also possible). The structure and content of the tables, as well as the "weight" of their positions, issue from contemporary scientific ideas and technological experience, and also take into account actually accumulating economic interest toward a given type of innovation. As an example we can present the summary of such characteristics and the system for their evaluation as they relate to the technology of foundation construction (Table 14).

The completeness factor T of a single invention is calculated as the ratio of the sum q of evaluations obtained by the given patent to the maximum possible sum Q in the table*:

$$T = \frac{q}{Q}; 0, 2 \leq T \leq 1.0.$$

The sum of the coefficients T for a group of n patents is called the reduced number of patents M :

$$M = \sum_{i=1}^n T_i.$$

If we summarize the reduced number of patents M issued in each year as a running total over the last 8-10 years and divide this sum by the total nominal number N of patents for this period (also calculated as a running total), we obtain the value of the generalized coefficient of completeness of the flow, T_{00} :

$$T_{00} = \frac{\int_0^t M(t) dt}{\int_0^t N(t) dt}; 0,2 < T_{00} < 1,0.$$

*If it was impossible to make an evaluation according to any particular position, then the points corresponding to this position and entering into q and Q are taken as equal to zero.

In accordance with the obtained values of the evaluations, the forecaster draws conclusions on the promise for practical application of one or another totality of technical decisions fixed in the patents. For example, the advisability of introducing a patent (or a group of technical decisions) with $T (T_{og}) = 1$ to 0.8 is very high; with $T = 0.79$ to 0.6 it is advisable; when $T = 0.59$ to 0.4 the advisability is low, and when $T = 0.39$ to 0.2 introduction is inadvisable. The author considers* that the range of forecast conclusions from this analysis is symmetrical with the depth of retrospection (patenting in 1958 corresponds to massive use of the invention in 1968; 1959 corresponds to 1969, etc.).

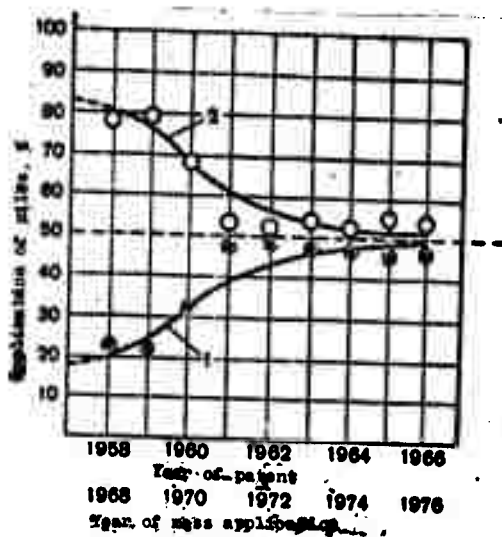


Fig. 36. Forecast of application of pile foundations. 1 - Per group of rammed piles; 2 - per group of driven piles.

An information model of the future redistribution of specific weight of two competing types of technical decisions is presented on Fig. 36.

*This position will be subjected to more thorough experimental checking.

The forecast data obtained by the author of the procedure in 1966 permit him to assert that in 1976 we can expect that driven piles will be used in 55 cases out of 100, while rammed piles will be used in 45 (in 1966 these figures were 20 and 80, respectively). Forecasts were obtained in a similar manner regarding the fact that at the end of 1976 dropped sewers and forced immersion shells will be applied in 47 cases out of 100, that drilled supports will be used in 32, and caissons (unmanned) in 21 cases. The forecast ascribed special promise to the use in construction of deep foundations of the so-called root foundation, whose construction imitates the branching root system of a tree.

Even several decades ago attention was turned to the possibility of judging the rates and nature of development of one or another branch of scientific activity with respect to data from the statistics of scientific literature [122, 123]. In the last decade, thanks to the formation of the information concept of the study of science within its framework, these "statistical assaults" expanded into systematic analysis of the informational phenomenon of science, in efforts to formulate and analyze unique informational models of growth of science.

The following are examined within the frameworks of these methods: the dynamics of growth of the number of scientific journals, the structure of the flow of publications and abstracts, the frequency with which printed works are used, and the dispersion and "aging" of publications. These data are compared with trends in the growth of the number of scientists, the size of appropriations for science, etc.

A similar type of tracing of trends is carried out on world, national, and regional scales. If comparison of the global picture with national data shows an essential difference in the quantitative evaluation, while the qualitative analysis of the region attests to its urgency for achieving specific national goals of scientific and technological development, the complex of observations can and must serve as a stimulus for making decisions — for organizational actions with regard to the scientific system, in order to increase the

activity and fruitfulness of the work of scientists in the desired directions of research [124, 125].

Students of science turn their attention to such essential circumstances as the similarity in the number of generalizing curves and the correspondence of many of them to the exponential "law of motion of science" to a period of doubling of the running total of data on the order of 10-15 years [21]. Continuation of more detailed investigation of the experience of different branches of science showed that exponential growth occurs only as a most generalizing trend, being manifested only in flows of information produced by large and mixed groups of scientific disciplines (for example, physics or chemistry as a whole).

In this case in those fields of science which live out a period of vigorous formation the rate of growth of the reserve of information is, as a rule, substantially higher. For example, the mass of works on methods of screening experiments (one of the branches of mathematical theory of planning experiments) has a doubling period equal to 5.4 years [126]. We will note that in differentiated directions of science not only the parameters of the growth curves, but their very character will change. Here each defined type of growth curve is connected with one or another specific determining stage of development of the given specific scientific discipline.

Also well-known are the proposals of the documentalists [G. G. Vorob'yev, 13] to conduct analysis of trends in the development of certain areas of scientific research on the basis of observations of information shifts in the flows of documentation which they generate. In this case it is proposed to use as an information signal, indicating an increase (or reduction) in the urgency of some particular area, the growth or reduction (over the last 3-5-10 years) of actual retrieval significance of the totality of coded document tags (it is determined by the intensity of interrogation and retrieval according to the given tags) as compared with the theoretical information load on the entire tag system. The latter represents the ratio of the number of objects with given tags to the total number of tags in a system for coding documents.

All such observations have a nature which is indirect in principle. When carrying them out it is especially important to combine the use of quantitative methods with deep penetration into the content and logic of development of the given scientific discipline.

Interesting ideas have cropped up in the area of information methods of analyzing the development of science in connection with the possibility (arising in recent years) of automated compilation of indices of bibliographic relationships (IBR) between different scientific publications (the "Citatindex" method) [127].

The annually published cross-indexed bibliographic listings of information on the most important divisions of science are compiled in a similar manner. Such is the basic function of an index. However, as frequently occurs in science, other possibilities, specifically important for the study of science, were quickly revealed. The IBR turned out to be a powerful and promising tool for analysis of trends in the development of science, diagnosis of the state of interdisciplinary communications, and forecasting of a number of phenomena in the vital activity of the scientific organism. The primary prerequisite of these IBR properties, valuable for the study of science, lies in the fact that the network of actual mutual effects constructed according to IBR data is an informational mapping - a model of the historical and logical network of connections of the actual process of development of science.

Using mathematical methods which are well known at the present, it is possible to analyze information networks of any complexity, obtaining objective data on the actual mutual effects, trends in the distributions of efforts of researchers, the intensity and direction of "migrations" of scientific information from one field of research to many others, etc.

In the conditions of a broad front of scientific research work, colossal volumes of information, and ever-growing value of interaction of sciences which are so typical of our times, even the well-informed

and competent researcher finds it difficult to trace operationally the changes in tactics of resolving scientific problems which are occurring in different countries. Changes in the structure of information flows provide a sensitive indicator. On the basis of an analysis of these changes it is possible to forecast the following: requirements which arise for the appearance of new specialized (or complex) scientific establishments, the need for existing and new periodicals, and the maturing isolation of new and relatively independent scientific directions. The structure, intensity, and directivity of the network of actual mutual effects also makes it possible to forecast expected (maturing) major scientific shifts in individual fields, while they sometimes provide material to explain the causes of poor results of one or another area [125, 128].

The experience of a number of Soviet investigators (V. V. Nalimov, R. F. Vasil'yev, Z. M. Mul'chenko, A. A. Korennoy, etc.) attests to the fact that the construction of information models based on IBR holds promise for purposes of analysis by methods of the study of science of trends primarily in the development of the fundamental natural sciences [129].

An especially important role in the complex of forecasting methods is assigned to the construction and analysis of different types of mathematical models of scientific and technological development. In the simplest case of statistical-probability simulation the forecaster approximates the future course of the examined process by means of one of the known statistical distributions. For example [130, 131], the life cycle of mass-produced technical equipment is, in a number of cases, well approximated by the normal (Gaussian) distribution (Figs. 37 and 38). Many phenomena and processes from the field of organization of science, its personnel, financial and informational security, are reliably characterized by the Lotka, Bradford, and Zipf distributions [132].

In the study of science considerable attention is paid to the analysis of the so-called growth curves, which in the ideal case follow the law of the exponent:

$$S_t = S_0 e^{kt},$$

where S_t are values of the growth indices of certain parameters of science; k is the exponentiability factor; t is time; and e is the base of natural logarithms.

In a case which differs in its characteristics, similar criteria of growth (number of scientists, magnitude of mastered scientific equipment, quantity of completed works, volume of useable scientific information, etc.) are described by the logist equation

$$S_t = \frac{b}{1 + S_0 e^{-kbt}},$$

where b is the maximum possible value for the given case. When $b \gg S$ this curve is close to the exponent. With growth in the value of S it is usually possible to note the point of the beginning of transition of the exponent to the logist (bend point).

A deeper analysis of the theory of "growth curves of science" [133] and objective examination of the present broad collection of actually formed curves of growth provides a basis to conclude that the following can serve as mathematical models of such curves: various functions assigned by the equations of the straight line, exponent, system of exponents, parabola, hyperbola, logist, the integral Laplace-Gauss functions, etc. The whole business lies in the validity of the accepted system of initial postulates with respect to specific process of development studied by means of growth curves.

One of the interesting efforts to give a generalized mathematical model for a group of related growth curves was undertaken by G. Schrauber, a forecaster from the GDR [134]. His idea can be outlined as follows.

There is a certain parameter P which expresses the fruitfulness of efforts to improve a given type of technical equipment. This parameter (fruitfulness) is a function of effort (the means M) expended on its achievement:

$$P = \psi[f(M)]. \quad (1)$$

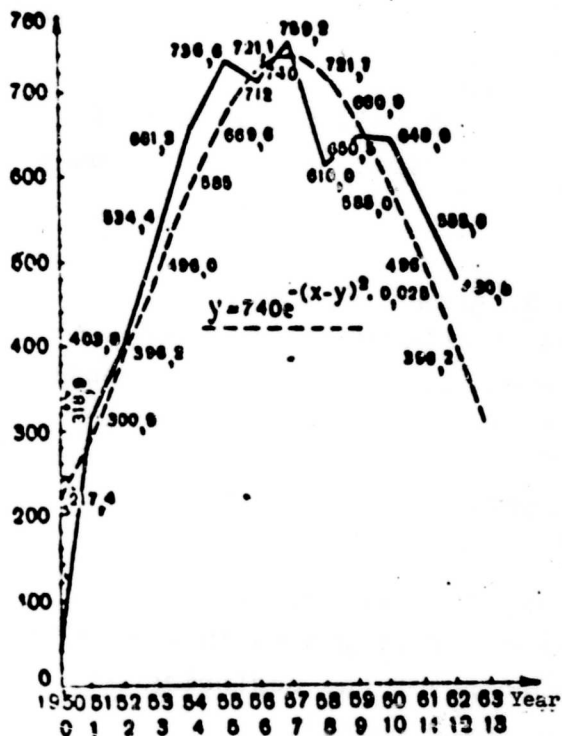


Fig. 37. Curve of the life cycle of production of one type of technology (production of motor scooters in the Western European countries).

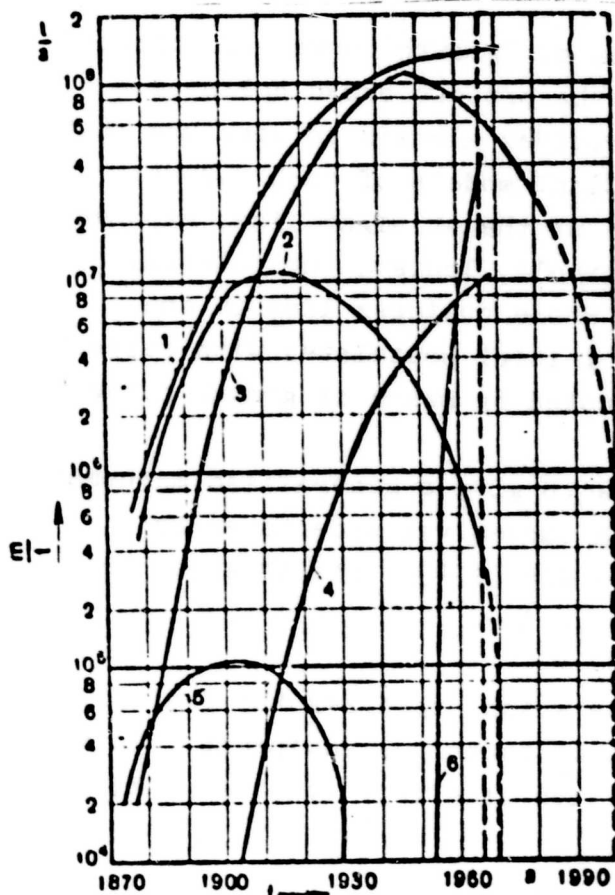


Fig. 38. Life cycles of a number of types of technology for smelting steel. 1 - Total production; 2 - Bessemer steel; 3 - Siemens-Martens steel; 4 - electrosteel; 5 - crucible steel; 6 - steel produced with oxygen introduced from above.

The fruitfulness of efforts within the limits of a single initial system of scientific and technological principles to be used has a certain limit P_{np} , for which the inequality

$$P < P_{np} \quad (2)$$

is valid.

The closer the value of P to P_{np} , the smaller the increment of the index dP to the increment of effort (means) dM :

$$dP = (P_{np} - P)dM. \quad (3)$$

Besides this, dP naturally depends also on efforts made previously:

$$dP = (P_{np} - P)f(M)\frac{dM}{dt}, \quad (4)$$

where $f(M)$ is a function which characterizes the effectiveness of the means used. A result of it and of the current increment of effort will be the relative rate of growth and the value of the index P , described as $g(t)$. Then equation (4) can be written in the form

$$dP = (P_{np} - P)g(t)dt. \quad (5)$$

Solution of this differential equation is

$$P = P_{np} - (P_{np} - P_0) \cdot e^{-\int_0^t g(t)dt}. \quad (6)$$

The exponent at e is the base of natural logarithms; it is approximately equal to

$$-\left[\frac{t_1 - t_0^n}{t_c}\right], \quad (7)$$

where n is a quantitative parameter characterizing one or another law of growth; t_1 is current time; t_0 is the time of beginning of counting; t_c is a constant which is called the time characteristic. It is characteristic in the respect that it reflects the degree of closeness of the developing process to P_{np} . The relationship

$$P = \left(1 - \frac{1}{e}\right)(P_{np} - P_0) + P_0 \quad (8)$$

occurs for it.

In a number of cases scientifically based physical values of P_{np} are known, and then t_c can be calculated with high accuracy; its approximate value from equation (8) corresponds to the following: with growing parameters $P \approx 0.63 P_{np}$, and with diminishing parameters $P \approx 0.37 P_{np}$.

In cases when $P_0 \ll P_{np}$ (when there is a significant reserve of increase of the index from the initial values up to limiting values — the most typical case), equation (6), with substitution of values of (7), can be written in the following form:

$$P = P_{np} \left(1 - e^{-\left(\frac{t}{t_c}\right)^n} \right). \quad (9)$$

Then two parametric relationships are introduced:

$$y = \frac{P}{P_{np}}; \quad x = \frac{t}{t_c}.$$

When they are considered the law of progressive growth of the quantitative index is described by the equation

$$y = 1 - e^{(-x)^n}. \quad (10)$$

Figure 39 shows a family of characteristic growth curves with various values of the index n . When this type of generalized model of growth curves is used for purposes of forecasting we proceed in the following manner: a) give an evaluation of the value P_{np} ; b) determine the value of t_c from analysis of actual trends of growth and by means of formulas (8) and (9); c) compute the value of the index n from the rise in the real curve of growth at $t = t_c$; d) assign the predicted running time and obtain an evaluation of the parameter P for it.

The outlined model was checked experimentally by Ya. Fenek*. He collected and analyzed data on the parameters of the majority of

*The data were processed on the "Minsk-22" electronic computer together with M. A. Mal'kov.

electronic computers issued from 1949 to 1967 in various capitalist countries. Then the expected limiting values were evaluated for electronic computers based on transistors: summation time $\sim 10^{-8}$ s, average operating speed $\sim 10^8$ op/s, working store capacity $\sim 10^8$ bit. Then Fenek, using a number of procedural approaches proposed by our collective, carried out statistical processing of the upper and lower values of these parameters and obtained leveled values of t_c and n for both curves for each parameter.

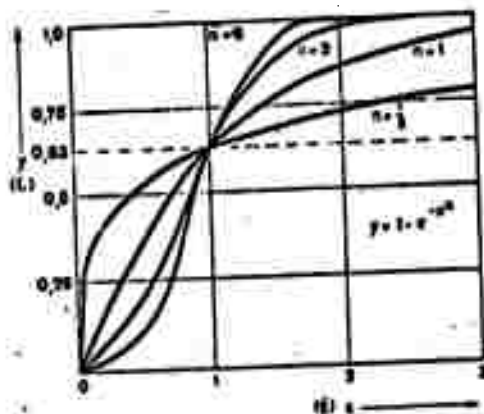


Fig. 39. Family of growth curves with different values of the index of the power function.

After this, working on the basis of the Schrauber model, he carried out extrapolations and obtained the expected values for each of the three parameters designated above. Figure 40 shows data relating to the growth in the values of the index of capacity of working storage of electronic computers.

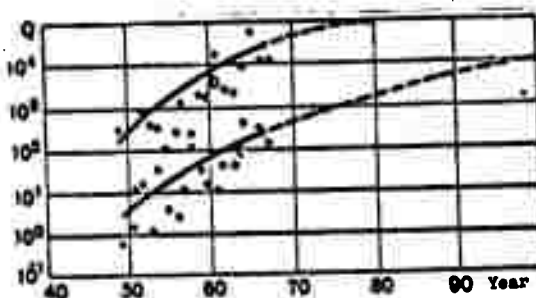


Fig. 40. Growth curves of upper (b) and lower (c) values of the index of capacity of working storage of electronic computers.

Fenek's data are in fairly good agreement with a number of other evaluations made by different methods, and they confirm the promise of work on improving the procedure for using growth curves in scientific and technological forecasting.

There exists yet another group of models which are used in the practice of forecasting scientific and technological development. This group consists in the construction of functional hierarchic networks of paths for achieving hypothetical goals in scientific and technological progress. These methods permit quantitative evaluation of the complexity of solutions of planned problems, the difficulty (in time and means) of achieving the forecast prospects, and also determining the probability of achieving one or another forecast accomplishments of scientific and technological progress. There is no need to prove that the presence of information of this type in a complex forecast of scientific and technological development makes it uniquely valuable for the practice of prospective planning.

An impelling motive for the development of one of these methods, known under the name Pattern*, was the effort to find the procedure for determining the optimum paths of realizing scientific and technological ideas. The immediate purpose of the development of this procedure by the American cooperation "Honeywell" (1963-1964) was to accelerate the process of creating new military scientific and technological systems [136]. Then the listings of objects of application was essentially expanded, although the first group of problems remained, as before, predominant [137]. The procedure provided that on the basis of analysis of a variety of data on forming trends and corresponding expert evaluations, a broad set of specific considerations could be obtained concerning future possibilities of scientific and technological development. By analyzing it in accordance with the requirements and resources of the country (or the firm), taking into account political, economic, and other general situations, experts compile a descriptive document - the "scenario" of the main prospects

*Acronym for the English phrase: "Planning assistance through technical evaluation of relevance numbers."

of scientific and technological development. After its preliminary approval by the competent levels the construction of a so-called tree of goals is carried out. Figure 41 shows an example - several branches of such a tree applied to the goal "prolongation of life."

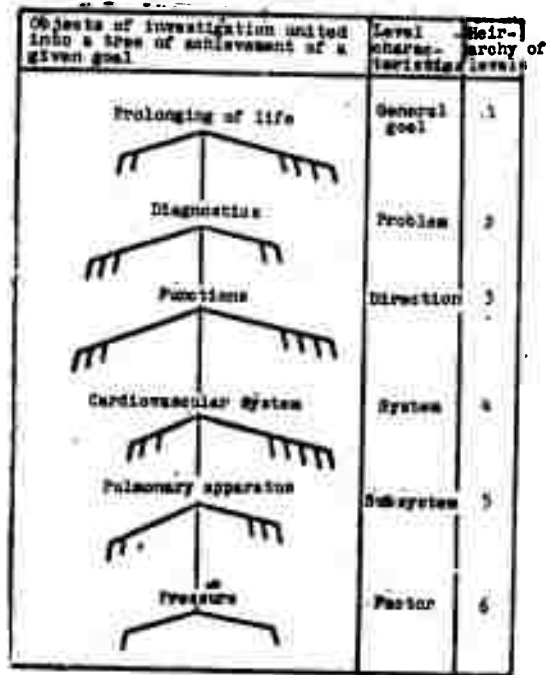


Fig. 41. Fragment of a "tree of goals" relating to the problem of "prolonging life."

An important circumstance is the fact that each "twig" of the tree (expected event) and each level of the hierarchy are assigned corresponding coefficients of relative significance of events and possible terms for their achievement by the method of expert evaluation. Also evaluated are the prospects for interdisciplinary cooperation, interdisciplinary communication, and the possibilities of organizing complex works. Here the experts base their work not only on their own common sense, experience, and intuition, but also on specific analysis of trends in research and development. The entire arsenal of available approaches from extrapolation to information and

statistical-probability simulation are used for this purpose.

The whole body of this information, very large in volume and not susceptible to survey and study "by hand," enters an electronic computer; here it is subjected to analysis, periodic corrections, and supplementation. It provides the basis for development of generalized specific quantitative evaluations of the forecast - for example, the probability of achieving different stages of an accepted prospect and the significance of this event for the general and particular goals.

In forecasting techniques the same problems are served by the ideas and approaches of the presently well-developed methods of "critical paths" (NPC, i.e., net planning and control, in the terminology used in our country). For instance, the following method is known for determining the relative probability of the onset of an event in processes of scientific and technological development [132]. For each of the united groups of possible events we calculate the number of paths fixed in the NPC system which will lead to the desired result. This number provides the starting point for subsequent determination of probability. The result which can be achieved by, for example, 15 different paths is evaluated as approximately twice as probable as the result which only 7-8 paths can lead to.

The methods of constructing and analyzing functional hierarchic models of paths of scientific and technological work are presently undergoing very vigorous improvement [139, 140]. With respect to recent literary data they number more than 30 [141]. Special attention of forecasters is drawn to those of such methods which permit evaluation of the relative significance of fundamental research for applied developments, and the significance of the latter for the complex of varied goals and subgoals of technical development.

The QUEST* procedure can serve as an illustration of this type of newly formulated approach to constructing functional hierarchic models.

*QUEST - acronym for the English phrase "quantitative utility evaluation of science and technology" [140].

It is based on the idea of successive construction of several mutually connected "goal - means" matrices. For example: "invulnerability of the coasts - technological systems required for this," "technical systems - direction of applied development," "applied development - direction of fundamental research." Each cell of these matrices obtains an appropriate evaluation of significance and probability of success in using the means to achieve the end. Then a special procedure is applied to realize quantitative analysis of the connections in the directions of research and development which will lead to the final goal.

While regarding critically the militaristic direction of the application of the QUEST procedure, we must not lose sight of its rational scientific content, which makes it possible to use an approach of this type for purposes of long-term planning of national economic problems of scientific research and experimental and design work.

In recent years the attention of students of science has been drawn to the possibility of using methods of operations research for analysis of experience in the development of science [142, 143]. With respect to problems of program and organizational forecasts an approach of this type begins to formulate efforts to create economic and mathematical models of the selection of variants of development and advisable distribution of resources, which is very urgent from the point of view of subsequent use of forecast data*.

As a whole the development of methods of simulation to be used by forecasts of science and technology is proceeding in the following direction: to an ever greater degree they synthesize within themselves rational elements from all other methods and approaches. This is a very promising route, since it opens the possibility of creating unified complex methods for successive development of exploratory, program, and organizational forecasts.

*We will meet this type of approach in the following chapter, where we will discuss the problem of selecting predictable directions of scientific and technological development.

CHAPTER V

URGENT APPLIED PROBLEMS OF SCIENTIFIC FORECASTING

1. The problem of selection

One of the specifically important and difficult methodological problems of scientific and technological forecasting is the problem of selecting directions of scientific and technological progress. The problems which it advances are resolved both during the process of forecasting work and on the completing stage of direct forecasting of science and technology. The number of variants and possibilities of development which are examined in the process of developing forecasts is very great. Researchers must pick out for inclusion in a summary forecast documentation of no more than 3-7 promising variants. The authorities who make decisions about the realization of forecast prospects and who formulate a prospective plan with consideration of them will, in their turn, usually decide on a part of these variants. Contemporary experience of forecasting permits generalized formulation of several basic groups of criteria by which forecasters are guided in halting their selection on one or another direction of scientific and technological development.

Criteria of forecast reliability. These criteria are used to evaluate the quality of developed hypotheses in order to screen out doubtful or poorly founded assumptions. Here the forecaster is guided to a large degree by common sense and his own intuition. Formalized methods exist for the probability evaluation of the degree of "risk" in making decisions on the selection of possible innovations [144, 145]. Experience shows that in any case it is necessary to

check the forecast from the point of view of the presence of typical forecaster errors - excessive self-confidence, insufficient consideration of closely related branches, preconceptions (concentration of attention on a single alternative only), invalidity of the limits of extrapolation, inaccuracies in calculations, etc.

The subjective nature of expert evaluations is also taken into account; in particular this relates to the determination of the time for accomplishing expected events. Usually a range of 12-15 years is optimum in this respect. It is possible to recommend a simple formula for selecting a realistic time $T_{\text{реал}}$ from among the most cautious, $T_{\text{ост}}$ and the highest possible, $T_{\text{в}}$, evaluations of the period of onset of forecast events:

$$T_{\text{реал}} = \frac{4T_{\text{ост}} + 2T_{\text{в}}}{6}.$$

Such an approach to evaluations of time has proved itself in the practice of net planning*. We carried out selective checking of this formula on scientific and technological data appearing in the thorough forecast "Resources of the USA in the Future" [146]. As is known, the average evaluation in these forecasts was made by extrapolation calculations independently of the presence of lower and high evaluations. However, conversion of these data according to the formula shown above gave, in 25% of the cases, a deviation of less than 5%, while in 70% of the cases of evaluation to 1980 and 2000 A.D. there was a departure from the calculated quantities of no more than 15%.

Here, naturally, the more massive the phenomenon being evaluated by the proposed formula, the closer was the coincidence with the calculated evaluations of the American forecasters. As an example we shall introduce one of the summary tables [146, Vol. II, p. 43] of the cited

*The concepts "optimistic" and "pessimistic" used in such cases in PCN theory are not always adequate here, since crisis situations may also be forecast. In this case, however, our persuasion that the forecaster is a well-informed optimist remains in force.

forecast (Table 15), which outlines the extrapolated values of the gross national product (in billions of 1960 dollars).

As is evident from the given data, the value of the medium evaluation of the forecast as calculated by the proposed formula differs from the forecast evaluations obtained on the basis of special extrapolation by less than one percent.

Technical and economic criteria of selection. Very frequently, in particular during the forecasting of accomplishments in technology and applied sciences, it is possible to find economic arguments worthy of merit for the selection of one or another direction of development. Naturally, in the case of evaluating the expected economic effect from hypothetical innovations 12-15 years in the future the usual procedure for calculating economic effectiveness of new technology must undergo essential changes.

During comparative economic evaluation of the forecast variants of technological systems it is mandatory to take into account the structure of the rate of capital investment and the expected returns from the innovations (Fig. 42).

It has been noted that as a program develops the cost of carrying on research and development grows in the general case exponentially from stage to stage; however, characteristic segments of this curve are subject to approximation by linear relationships with sufficient accuracy [147]. On the considered diagram this is reflected more specifically: AB - stage of applied research; BC - development and experimental checking of the system; CE - production of lead specimen; ED - introduction into operation; BFGH - production and sale of the new technological system.

The equivalent period of capital investment within which all expenditures are, as it were, introduced at one time and also immediately reimbursed, equals OF (F is the point of "equilibrium," FH - period of reimbursement of interest).

Table 15.

1950	1960	Category of forecast evaluation	Calculated value of \bar{C} and its deviation, \$	Calculated value of \bar{C} and its deviation, \$	Calculated value of \bar{C} and its deviation, \$	Calculated value of \bar{C} and its deviation, \$	Calculated value of \bar{C} and its deviation, \$
363	501	Lowest evaluation (L)	710	965	1160	1650	2216(0.7)
		Middle evaluation (M)	706	1060(0.1)	1510	2200	
		Highest evaluation (H)	798	1250	1980	3120	

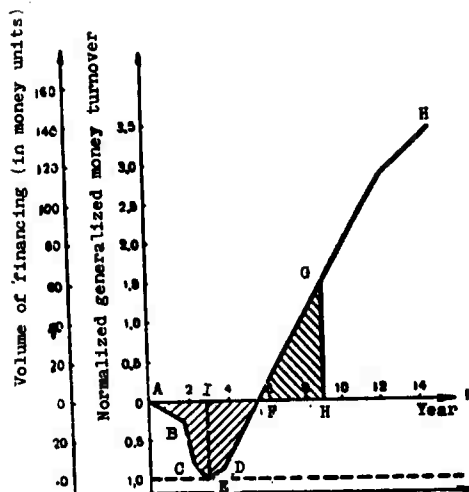


Fig. 42. Generalized diagram of the dynamics of capital investment and economic return from technological innovation.

The following approach is frequently used for comparative evaluation of several variants:

a) a classifier of technical and economic criteria is developed (size of capital investment, expected effect, achievable technical level, time, required production conditions for realization, etc.);

b) for each group of criteria an evaluation is fixed (in points) in a special evaluation table for the possible state of the forecast variant. For example [148, 149], with respect to the criterion "Expected influence of the innovation on the technical level of production" the following possible states are fixed and an evaluation is assigned to them in points: simple expansion of assortment 1, issue of products of increased quality or a change in existing technology 2, elimination of scarcity of products of this type 3;

c) each of the variants proposed for examination is evaluated by a group of competent experts in accordance with the classification tables;

d) the total points received by each variant are compared and a decision is made about one or two variants to be included in the

plan of operations in accordance with specific financial and industrial conditions.

In forecasting practice simplified evaluation formulas are also applied for these purposes; they permit consideration of a small number of essential factors. An example is the Pacifikko formula [150]:

$$E = \frac{R_t R_c G}{N},$$

where E is the expected effect; R_t is the probability of achieving technological success (as a fraction of 1); R_c is the probability of achieving commercial success (as a fraction of 1); G is the expected general approach; N is the total cost of the proposed project.

The variant is considered worthy of attention in the case when the value $E \geq 2$.

Foreign experience justifies the use of a formula of this type for evaluations of assumptions which in principle carry no very high risk and which are calculated for realization in the relatively near future (~5 years).

The Disman formula

$$M = R_t R_c \sum_{i=1}^n \frac{I_1}{(1+r)^i}$$

is intended for evaluation of maximum justified expenditures with consideration of any number of years required for realization of the variant [151]; here M represents the maximum justifiable expenditures; i is the number of years required for realization of the forecast ($i = 1, 2, \dots, n$); I_1 is the size of income accumulated at the end of the year for each year; r is the standard of profit.

These and similar formulas are not perfect even in the conditions of capitalist economics, for which they were created*. Under the

*R. Zayler [?] writes [152, p. 183] with respect to quantitative methods of selecting projects: "The management of companies keeps formulas used for calculation completely secret... their main distinction is the weighted values assigned to individual factors."

conditions of the economics of Socialist countries it remains for us to develop a system of generalized economic criteria for evaluation of alternatives of scientific and technological development susceptible to forecasting over the long view [169, 170].

This same requirement relates also to the existing foreign experience in constructing economic and mathematical models for evaluating processes of scientific and technological development and to experience in application of methods of operations research to the evaluation of hypothetical variants of forecasts. It seems to us that the problem of first priority in our case on this path is the accumulation of experience in constructing evaluating functions for typical situations and phenomena of the progress of Soviet science and technology.

For the comparative analysis of variants in scientific and technological development which are to be forecast, we consider the use of the approach formulated by Academician V. A. Trapeznikov during analysis of the effectiveness of automation [153] to be very promising. In accordance with this idea, which possesses significant generality for different fields of scientific and technological progress, an index designated by the author as the coefficient of progressive capital investment (КПВ) is used as the economic criterion for selection of variants.

By analyzing the characteristics of the increment of productivity of labor (for the natural gauge - pure production) as a function of the growth of capital investment, we can obtain the evaluation

$$\text{КПВ} = \frac{\Delta\Pi_T}{\Delta\Pi_\Phi},$$

where $\Delta\Pi_T$ is the increment dependent upon technological progress; $\Delta\Pi_\Phi$ is the increment depending on the growth in the supply of capital. Experience in evaluating the technical level of various variants of "establishments of the future," accumulated under the leadership of V. A. Trapeznikov, confirmed the possibility of successful use of the

economic criterion characterized above in scientific and technological forecasting*.

System criteria. These criteria for evaluation of possible development are based on consideration of the interests of the hierarchically highest levels of the system for a given case. It is proposed that the promise of a new direction of fundamental and theoretical research be evaluated in terms of the degree of influence which it may render on other sciences [155]. The more significant the changes which may be expected in closely related fields, the higher the evaluation of prospects for exploration in the new direction of a given science. The degree of promise of applied directions of scientific research is evaluated in terms of their place and role in a broader system: "science - technology - production." We represent one of the criteria of evaluation of a situation of this type as the ratio of the rate of development by which technology outstrips production to the rate by which science outstrips technology [156].

This ratio can be written in the following form:

$$\frac{dS}{dt} > \frac{dT}{dt} > \frac{dP}{dt},$$

where each term designates, respectively, the speed of development of mutually connected branches of science, technology, and production.

In essence it was precisely this peculiarity of scientific and technological policy which Academician M. V. Keldysh had in mind when he spoke of the need to "guarantee to Soviet technology a higher rate of development than that of heavy industry, and to develop the natural sciences at rates, in their turn, which outstrip the development of technology and the technical sciences." [157].

*Interesting thoughts on the evaluation of the level of utilized knowledge and the effectiveness of the yield of live labor embodied in technical equipment are expressed in the development of these ideas by I. G. Kurakov [154].

This important principle and its somewhat unusual mathematical interpretation as inequality of derivatives rests on a sound foundation. "Science," D. Bernal noted in his time, "should be regarded as the second derivative of the total product. Actual production can serve as the initial measure in judgements on financing of science. Broadening or improvement of production by ordinary technological methods is the first derivative. It is represented by the rate of change of existing production processes. The second derivative - the rate of change of the first - is in fact that which is produced by science" [158].

In the development of the outlined approach, an interesting idea was expressed by the Soviet student of science B. G. Kuznetsov [159]. On the basis of the principle that the optimum structure of production should be characterized by increasing productivity of social labor P , the first derivative of P should be, in the case of progress, positive:

$$\frac{dP}{dt} > 0.$$

A planned economy must ensure steady growth of this rate $\frac{d^2P}{dt^2} > 0$. This second derivative is ensured by the totality of the effect of technical progress and applied research. The fundamental sciences are called upon to guarantee a trend toward steady acceleration of this progress (the third derivative):

$$\frac{d^3P}{dt^3} > 0.$$

The general trend of scientific and technological progress is such that the development of production and technology are evermore directly dependent on the higher derivatives. This life requirement (the condition of progress), having the character of a natural law, is satisfied by the intellectual potential of science growing out of the resolution of fundamental problems of science. "The optimum structure of the national economy," writes B. G. Kuznetsov, "is a structure which gives not the maximum value of P , but the maximum value of the derivatives $P \cdot \dot{P} \cdot \ddot{P} \cdot \dots$ ".

We will pass over the possible zero value of this function if on some particular step the rate of change of P is stabilized and the following derivative of it becomes zero*. Here the important thing to us is the idea itself - the effort to include science into the structure of a broader system of a higher level.

Clearly, everything which has been said serves as a sufficient argument for considering the problem of studying the rate of motion of scientific developments from "purely" scientific ideas to their practical embodiment as one of the most important considerations for research on scientific and technological forecasting. In any case, we assume that students of science working in nations with a planned economy and a unified state scientific and technological policy will make this problem the object of the most active development.

From the principle pointed out above there follows also a system criterion for forecasting in the field of direct development of new technology. The criterion for selecting variants can be based here on evaluation of possible prospective changes in the system of lags, i.e., in the rate of materialization of technical ideas which are comparable in significance. Figure 43 shows a typical system of lags with regard to two prospective forms of technology in a comparison of Great Britain/USA [160]. In accordance with this criterion preference should be given to that predicted variant which, other conditions being equal, opens the greatest promise of economy in the socially required time for its realization.

Criteria of policy. This is a broad class of criteria which are conditioned by the social structure of society, its internal and external policies, ideology, and other factors which express the relationship of the given state and society to science and also express the national goals imposed on science.

*This difficulty can be avoided by perfecting the structure of the most complete function: $P \cdot P \cdot P \cdot P$. This is made necessary also by the fact that in the proposed general form it is not intended for direct calculations.

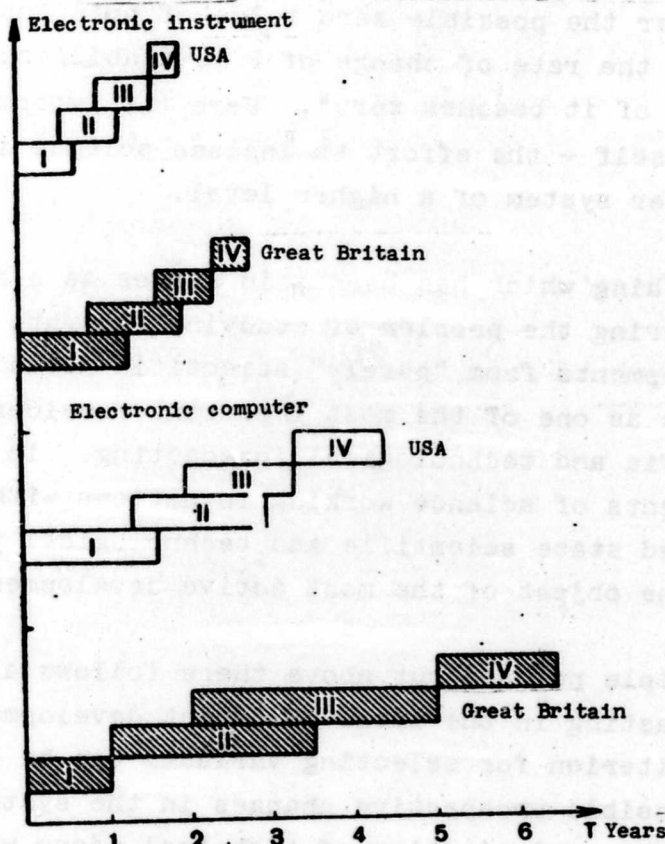


Fig. 43. Diagram of lags for two contemporary objects of scientific and technological progress. I - Bringing scientific development to the stage of design assignment; II - designing and creation of an experimental industrial prototype; III - development of technical documentation and preparation for lot production; IV - production tests and evaluation of the technical and economic indices of the completed development.

One specific form of criteria of this class is known in the form of priority criteria. Not only the rather important factors of national prestige, but also deeper economic and defense circumstances make criteria of this type very real. The problem, however, lies in the fact that at present not every country, taken separately, is able to maintain world priority over the entire complex of scientific and technological prospects as indicated by forecasts. Here the "small" and "large" countries are distinguished from one another only by the

variety and the set of directions which is available to them, and not by the existence of the actual problem of selection as such [161].

From this there follows the need to include in the composition of strategic scientific doctrine of each country ideas about those directions in which the given country does not consciously set itself the task of leading the world, but is oriented to preferential application of international scientific and technological experience. In this case the problem of mastering the newest achievements of world science is not eliminated, since the achievement of success in using the results of science inevitably assumes the existence of a sufficiently high level of scientific potential within the country.

Even more definite is the need to know the fields in which the achievement of world supremacy is recognized as a national goal. In these cases the criteria for selection of forecast scientific directions will take into account the popular wisdom: "When you are following a trail you cannot be first. If you are in the lead, you cannot be overtaken." Here the preference, obviously, will be given to paths which are new in principle. In this case it is necessary to proceed consciously to an essentially higher level of risk - to a reduced probability of individual predicted variants and essentially greater funding of realizable programs of research and development.

To the above we must add that international cooperation of scientists of the Socialist countries on both a bilateral and a multilateral basis within the frameworks of the nations of the Council for Mutual Economic Aid [CMEA] permits significant expansion of the scale of development in all of our countries with regard to especially promising directions of scientific and technological progress.

The examined criteria for selection of forecast variants (their composition is subject to refinement) [148, 158] have a nature which differs significantly from group to group. In the process of practical utilization of such a broad range of criteria, both now, and probably, in the future a significant role will be played by intuition, logic,

and common sense of leaders who make the decisions on selecting the forecast variants. In many essential aspects, these procedures are not subject (at least at present) to algorithmization.

For example, it is possible with complete justification to include in the group of system criteria the moral and ethical criteria assigned by the Socialist system of society; these criteria result in the rejection of a number of predicted possibilities of science in certain countries (creation of artificial stimulators of a sense of well-being, narcotics, heart transplants, etc.) [162], while in other countries this approach is encouraged (work on creating bacteriological weapons in the USA).

The search for quantitatively defined and, where possible, more objective criteria for selecting forecast variants and also the development of procedures for their application which can be algorithmized represent one of the most urgent applied problems of contemporary scientific and technological forecasting.

Efforts to develop procedures of this type are found, in particular, in the works of Soviet forecasters [163, 164]. The first of these gives a refinement of the idea, which we advanced, of creating a "Library of Technical and Economic Characteristics of Future Mining Equipment," from which hypothetical levels of complex mechanization and automation are formulated during calculation of prospective variants of new coal mines; in connection with this optimum parameters, with respect to the prospective time interval, of specific elements of projected undertakings are calculated.

In the general case the number of alternative variants of mechanization of stripping operations can include those types of mechanization which are already applied in these conditions and, consequently, which can be characterized in more detail on the basis of statistical data and appropriate calculation. In this case the parameters which characterize the load on the i -th longwall with the k -th form of mechanization corresponding to the t -th year - P_{ik}^t - could not properly be extended to the $(t + 1)$ -th year in connection

with those quantitative changes which, other conditions being equal, occurred under the influence of technological progress; in the given case this is expressed in the mastery of technology, in the improvement for removal of coal, modernization and improvement of individual machine units, etc. Therefore the statistical parameters which characterize the limits of values of load on stripping faces in the $(t + 1)$ -th year should be corrected by a coefficient which takes into account the increase in the load caused by technological progress, Π .

Then, if \bar{P}_{ik}^t and P_{ik}^t are the upper and lower limits of the values of loads on the i -th stripping face with the k -th form of mechanization, calculated by the statistical method in the t -th year, the same parameters for the $(t + 1)$ -th year can be determined according to the formulas

$$\bar{P}_{ik}^{(t+1)} = \bar{P}_{ik}^t \Pi_k^{[t, (t+1)]}; \quad (1)$$

$$P_{ik}^{(t+1)} = P_{ik}^t \Pi_k^{[t, (t+1)]}. \quad (2)$$

Here, obviously, at the moment of planning the value of coefficient Π_k as a function of the type of mechanization in the period for its mastery will be different. It is evident that in the first years of introduction of a new type of mechanization it will be greater than, let us say, on the 8th-10th years, when for practical purposes its capabilities will already have been exhausted to a significant degree.

However, it must be noted that, depending upon the type of mechanization, the structural features, and conditions of its utilization, the process of mastering it and, consequently, the value of the coefficient Π_k will vary. Therefore during specific calculation of the development of mining operations it is advisable to use relationships which take into account the type of mechanization, the period for its mastery, and the conditions in which it will be applied.

Obviously, according to formulas (1) and (2) the increase in output in successive years will comprise the following:

$$\begin{aligned} \Pi_{ik}^{[t, (t+1)]} &= \frac{P_{ik}^{(t+1)}}{P_{ik}^t}, \\ \Pi_{ik}^{[(t+1), (t+2)]} &= \frac{P_{ik}^{(t+2)}}{P_{ik}^{(t+1)}}, \dots, \Pi_{ik}^{[(T-1), T]} = \frac{P^T}{P^{(T-1)}}. \end{aligned} \quad (3)$$

Here the following inequalities are valid for the obtained coefficients:

$$\Pi_{ik}^{[t, (t+1)]} > \Pi_{ik}^{[(t+1), (t+2)]} > \dots > \Pi_{ik}^{[(T-1), T]}. \quad (4)$$

The difference between each successive coefficient and the preceding one comprises the quantity $\Delta \Pi_{ik}$, which characterizes the degree of mastery of the new technology. Its absolute value diminishes with a growth in the period of operation of the machine.

If we consider the period of existence of stripping equipment to be 5-7 years, the value of $\Delta \Pi_{ik}$ for each successive year can be determined approximately as follows

$$\Delta \Pi_{ik}^{[(t+1), (t+2)]} = \frac{\Pi_{ik}^{[t, (t+1)]} - \Pi_{ik}^{[(t+1), (t+2)]}}{1 + t_{\text{en}}}. \quad (5)$$

Then

$$\left. \begin{aligned} \Pi_{ik}^{(t+2)} &= \Pi_{ik}^{(t+1)} - \Delta \Pi_{ik}^{[(t+1), (t+2)]} \\ &\dots \dots \dots \\ \Pi_{ik}^T &= \Pi_{ik}^{(T-1)} - \Delta \Pi_{ik}^{[(T-2), (T-1)]} \end{aligned} \right\},$$

where t_{en} is the time during which introduction of the k-th type of stripping equipment was carried out.

Thus, by successive solution of equations (5), (6), (1), and (2) it is possible in each individual case to forecast the technological progress in a quantitative expression.

It is obvious that as the value of the coefficient Π_k diminishes the technical capabilities of the given type of equipment are exhausted and its previously indisputable effectiveness becomes problematical

as compared with more productive and improved types of equipment which may be appearing.

The algorithm [165] developed for solution of such problems provides (by means of technical and economic analysis) for solution of the problem of the advisability of transition from one qualitative state (old equipment) to another type, which corresponds to making a decision on selecting the forecast variant of the development of technological systems.

In the work by B. A. Lapin which we cited, on the basis of a number of previously outlined ideas on expert evaluations and functional hierarchic models the following procedure for organizing forecasting work and selecting future directions, research, and developments is proposed.

1. A general "goal - means" matrix is formulated, in which the relative significance of each subgoal p is evaluated (Table 16) by a special group of experts (in fractions of 1).
2. The relative significance of two basic groups of means of achieving the indicated goals is evaluated by the experts (Table 16).
3. In the new matrix (Table 17) these two groups are now treated as goals. The basic directions of research and development which may lead to achievement of these goals are formulated. A new special group of experts provides for these directions a corresponding evaluation of relative significance for 10-15 years.
4. On the basis of analysis of the obtained summary evaluations of significance, B. A. Lapin proposes to solve questions concerning the proportions in distributions of resources and other problems of selection.

Table 16.

Elements of level II - general means for achieving goals	Elements of level I - basic goals of technological progress			Total $\rho = 1,00$
	Increase in economic effect due to introduction of new technology $\rho = 0,30$	Increasing the technical level of production $\rho = 0,45$	Ensuring the supremacy of Soviet science and technology. $\rho = 0,25$	
Conducting scientific research.....	0,50 (0,30 \times 0,50 = 0,15)	0,40 (0,45 \times 0,40 = 0,18)	0,70 (0,25 \times 0,70 = 0,175)	0,505
Realization of scientific achievements and new technology in the national economy.....	0,50 (0,30 \times 0,50 = 0,15)	0,60 (0,45 \times 0,60 = 0,27)	0,30 (0,25 \times 0,30 = 0,075)	0,395
In all	1,00	1,00	1,00	1,00

Table 17.

Elements of level III - basic directions	Elements of level II - basic efforts of branches		Total $p=1,00$
	Carrying out scientific research $p = 0,505$	Realization of scientific achievements $p = 0,495$	
Creation of a unified series of turbohydrogenerators of increased reliability, increasing the unit capacity of aggregates, reducing the cost per installed kilowatt of power.....	0,20 (0,505 × 0,20 = 0,1010)	0,10 (0,495 × 0,10 = 0,0495)	0,1505
Creation of new unified series of economic and highly reliable electrical dc and ac motors.....	0,30 (0,505 × 0,30 = 0,1515)	0,40 (0,495 × 0,40 = 0,1980)	0,3495
Increasing the nominal parameters, operating speed, working temperature range, service life, and reliability of high-voltage equipment.....	0,10 (0,505 × 0,10 = 0,0505)	0,20 (0,495 × 0,20 = 0,0990)	0,1495
Creation of reliable lifting and transport equipment for operation in various climatic conditions, increasing the power of electric locomotives and their average speed.....	0,10 (0,505 × 0,10 = 0,0505)	0,10 (0,495 × 0,10 = 0,0495)	0,1000
Creation of new types of light sources and increasing their technical level.....	0,10 (0,505 × 0,10 = 0,0505)	0,10 (0,495 × 0,10 = 0,0495)	0,1000
Introduction of leading technology, mechanization, and automation of production processes in the branch	0,20 (0,505 × 0,20 = 0,1010)	0,10 (0,495 × 0,10 = 0,0495)	0,1505
In all	1,00	1,00	1,0000

In our view, a significant weakness of the outlined approach is the following: the absence of consideration of many specific factors of potential scientific and technological significance, the static (single-instant) of the factor of the time during which the significance of the analyzed forecast variants will change, and the absence of consideration of the dynamics of development of a direction as a function of the fraction of means invested in its realization, etc.

As the fundamental idea which illustrates the possibility of calculating factors of this type we can propose the following approach, whose goal is to reduce the problem of selection to the problem of evaluation of variants by means of linear programming. This idea flows from the methods of forecasting operations which we discussed in the preceding chapter and can be regarded as the application of economic and mathematical methods to problems of a program and, especially, an organizational forecast. We will outline it in the form of several successive stages of the concluding organizational forecast.

I. Statement of the problem. Let there be N variants (1, 2, ..., J , ..., N), validated by research and program forecasts, of prospective directions of scientific research work relating to a single field of scientific and technical progress. Using the general criteria of selection listed above, we shall carry out a preliminary analysis and selection of variants in such a manner that the variants known to be unacceptable or to exceed the framework of economic capability of the requester* will be discarded. Consequently, all N variants of predicted work are, in principle, desirable for the requester and the following relationship is valid for them:

$$\sum_{j=1}^N a_j \leq M_p, \quad (7)$$

where a_j is the cost of realization of the j -th variant of the forecast;

*Under "requester" we will understand any level of responsibility which has the authority to put forward prospective plans of scientific research work and to distribute resources according to their directions (Goskomitet on science and technology, Academy of Sciences of the USSR, Ministries, etc.).

M_p is the total magnitude of resources which the requester can assign to realization of a complex forecast program of interest to him.

Each of the forecast variants has its own probable time of accomplishment; besides this, the requester has available ideas about time t_j during which he wishes to obtain the predicted result in accordance with requirements for innovation of existing systems and carrying out of programs.

II. Formulation of an hypothesis about possible levels (rates) of financing. We shall introduce an initial postulate that the term for accomplishing a realistic forecast variant and its significance can vary as a function* of the scales of efforts applied to its realization.

Below we will examine the relative magnitude of financing as a gauge of the scale of efforts. This is done in order to simplify the exposition of the principal idea of the approach. In reality the specific procedure which we have developed also takes into account the number of newly enlisted specialists and the magnitude of that portion of the available scientific potential which can be switched over to realization of the forecast program of scientific research work.

The first three methods of distributing resources, M_p , for each of the proposed variants of forecasts N consist of this combination: $2a_j, a_j, 0.5a_j$. With consideration of relationship (7) we obtain the

*As the first approximation we take the hypothesis of a linear dependence between the magnitude of applied efforts and the characteristics of the achieved results. Other and more exact approximations of this relationship are known [152, 166]. For example: $E =$

$Rt^a \cdot e^{-bt}$, where E is the expected success (in the economic equivalent); R is the magnitude of resources; a is a parameter which characterizes the shape of the curve of the fulfillment cycle; t is time; e is the base of natural logarithms; b is a constant which characterizes the rates of scientific and technological progress in the given field. At first we wish to avoid certain methodological difficulties connected with the utilization of such formulas.

corresponding set of volumes of resources for all of the considered variants. In such a case the number of variants of rates of consumption of resources will be $i = 1, 2, 3, \dots$. Generally speaking, $i = 1, 2, \dots, n$. Experience shows that for selection of the optimum distribution it is sufficient to examine 6-7 variants, usually falling within the limits of the first combination.

Below we shall move on to obtaining specific data required to construct the evaluation function.

III. Evaluation of the degree of perfection of a variant of the forecast and proposed dynamics of its realization. A properly formulated and instructed group of experts produces an evaluation (in points) of the level of the contemporary state (degree of perfection) of each developed forecast variant. Here they use special tables, of which an example is presented below (Table 18)*.

After evaluating the existing level L , the forecasters use the same table to answer the question: "How will level L change in the course of the next 2-3 years if double the effort ($2a_j$) is expended on realization of the forecast as is provided in the predicted proposal?" The same is done for $1.5a_j$, etc. over all the variants of distribution of resources - the rates of consumption of means. Thus we obtained the value ΔL_1 for time Δt equal to two or three years.

IV. Evaluation of the possibility of timely use of the results of the forecast variant. It is known that in the general case the cycle of fulfilling scientific research work is described by a curve which is close to the normal (Gaussian) distribution. We shall accept as sufficient for our conditions a trapezoidal time function as the approximation of the description of this cycle (Fig. 44).

*Tables of this type must possess sufficient generality for applicability to different scientific research operations, but formulation of the definition of the level can contain positions which are specific for the field of research.

Table 18.

Level of perfection	Definition of characteristic features of each level	Evaluation in points from 0.2 to 1.0
1	The problem is defined, its basic concepts are formulated; however, methods of solution are known only in their general features	0.2
2	The forecast is based on available special research, which indicates potential realizability of the variant of scientific research works; possible specific approaches to the solution are also known	0.3
3	The optimum variant of approach to solution of the problem is determined on the basis of consideration of experimental data and analytical calculations carried out by scientists working in the given field	0.4
4	In addition the forecast contains a developed program of specific exploratory research and experimental developments which has a high probability of successful realization	0.5
5	In addition to the characteristics listed above the forecast variant also has formulated presentations on the expected parameters of the results and specific requirements for them with regard to possible users	0.6
6	In addition the forecast contains fixed prospective types and specific forms of expected results, but still requires manifold checking of their realizability and correctness	0.7
7	The correctness and realizability of the predicted types and forms of results are proved, and the reserve of scientific and technological works and industrial experience is sufficient for direct realization of the noted prospects	0.8
8	The forecast contains the possibility also of fixing the general readiness of existing experimental base and technological equipment for realization of the noted prospects	0.9
9	The level of development of the forecast corresponds approximately to the requirements presented for design as assigned for direct realization, and can be transferred for immediate realization. The scientific, technological, and industrial potential sufficient for this purpose is available	1.0

On this diagram t_j is desirable time of beginning of practical use of the forecast results or the time when they are joined with stages for fulfilling of broader programs by the leaders, as fixed by the requester.

For each of the N forecast variants and according to all n combinations of distribution of resources, this diagram is used to evaluate two time functions $f(t_c)$ and $f(t_H)$: the first is from the point of view of applied use of the expected results in technological systems, while the second works from the point of view of scientific research interests (reserve stock and joining). The need for two evaluations of this type arises from the fact that the results of the predicted variants must in principle possess not only applied but also general scientific significance.

The evaluation is carried out as follows. If the probable time of realization of the forecast (at a given rate of use of resources) lies within the limits of $0.5t_j$ to $1.5t_j$, the evaluation is given 1 point. With higher values of forecast time the evaluation is correspondingly reduced, since production or research will be required to wait for this result. The evaluations also reduced at very small values of the time, since while the given forecast result awaits utilization it can become obsolete if other and more promising results are obtained for the given purposes.

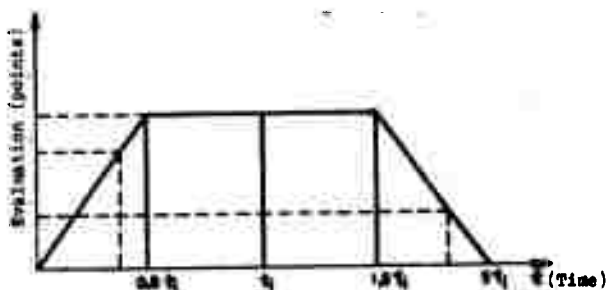


Fig. 44. Approximation of the time function for realization of a predicted variant of scientific research work.

V. Evaluation of the generalized significance of the solution.

To accomplish this we first construct a "goal - means" matrix (which we described in the second section of Chapter IV), where the weight of each cell is designated on the basis of the procedure for processing data outlined there. The experts subsequently specifically examine the internal content of the forecast variants and, using the evaluation matrix, fix the contribution of each of the elements of the forecast. The sum of all obtained evaluations comprises the generalized evaluation of the significance, C_j , of the composition of the predicted solution.

VI. Evaluation of hypothetical summary results. The contribution of the forecast variant to solution of production or applied technological problems which arise due to direct requirement for development of a given forecast is evaluated according to a special characteristic table containing (like Table 19) specific unique characteristics of each level of evaluation. We give a list of these levels in short form.

The forecast relates only to the given field....	0.1
An indirect contribution to particular aspects of the field is expected.....	0.2-0.3
Improvement in the characteristics of existing systems, without changing their principles, is expected.....	0.4-0.5
A significant contribution capable of changing the operating principles of existing systems is expected.....	0.6-0.7
An important contribution is forecast, such that if it is not carried out the complex of operational indices of the systems will be significantly impaired (failure to meet requirements will be increased).....	0.8-0.9
An extremely important contribution - a solution for which there is no substitute and whose absence will disrupt the functioning of the systems.....	1.0

Evaluation of b_c is given for each forecast variant.

VII. Evaluation of the contribution of hypothetical summary results to raising the scientific and technological potential and to

scientific reserve. The table for such an evaluation of results contains the following characteristic points.

Possibility of better understanding of the problem.....	0.1-0.2
Improvement in research methods and refining of known scientific positions.....	0.3-0.4
Formation of an essentially new approach to solution of the given class of scientific problems	0.5-0.6
Discovery of new possibilities for using known scientific principles.....	0.7-0.8
Obtaining potentially enormous achievements, leading to discoveries of new principles and phenomena.....	0.9-1.0

Evaluation of g_{μ} is given for each forecast variant.

VIII. Equations of the general potential significance. These are formulated and solved for each j -th forecast variant at each i -th rate of use of resources. In accordance with contemporary concepts of operations research, and also according to certain approaches which were delineated in work [167], the equation of the general potential significance of one forecast variant can be written in the following form:

$$V_1 = \frac{\Delta L_1}{\Delta t} \cdot C_j \left[\sum_{i=1}^n f(t_c) b_c + \sum_{i=1}^n f(t_{\mu}) g_{\mu} \right]. \quad (8)$$

All data for solution of this equation are already available to us. Now we will pass on to the stage of actual formulation of the problem of linear programming.

IX. The problem of linear programming. This problem consists in the fact that with given resources the requester ranks all available forecast variants N with n combinations of resource distribution in order to obtain the maximum scientific and technological effect from realization of the entire complex of scientific research works in which the requester is interested. Thus, we must maximize the purposeful [total?] function

$$v_1 x_1 + v_2 x_2 + \dots + v_1 x_1 + \dots + v_n x_n = V_s, \quad (9)$$

where x_1 is the relative volume of scientific research work to be financed at the 1-th rate of expenditure of resources; V_s is the total significance of the entire program.

We shall set the limiting conditions.

First:

$$a_1 x_1 + a_2 x_2 + \dots + a_1 x_1 + \dots + a_n x_n \leq M_p. \quad (10)$$

Second:

$$\left. \begin{array}{cccccc} x_1 & + & x_2 & + & x_3 & + & x_4 & + & x_5 & + & x_6 & = & 1 \\ \vdots & & \vdots & & \vdots & & \vdots & & \vdots & & \vdots & & \\ x_{n-5} & + & x_{n-4} & + & x_{n-3} & + & x_{n-2} & + & x_{n-1} & + & x_n & = & 1 \end{array} \right\}. \quad (11)$$

Third:

$$x_i \geq 0, \quad (12)$$

where $i = 1, 2, \dots, n$.

X. Solution of the problem of linear programming. Simultaneously with solution of this problem, we accomplish solution of the problem of selecting forecast variants according to their preferability and also the problem of the optimum (from the point of view of obtaining the maximum summary effect) distribution of the resources of the requester between various proposed forecast variants of scientific research work. Analysis of these data should permit the requester to make decisions on formulating a prospective plan of scientific research and development which has a sound scientific basis and will be most successful in the specific situation.

Experience in solving other similar complexes of linear programming problems attest to the fact that even when the values $3 \leq N \leq 6$ and $3 \leq n \leq 6$ it is advisable to solve these problems with the aid of an electronic computer. By using machines with an adequate storage capacity it is possible to accomplish systematic reevaluation of

forecast variants when there are changes in capabilities or growth in requirements.

2. System of forecasts

Each of the forecasting methods known at present has its strong points, weak points, and limits of capability. However — and we wish to specially emphasize this — *taken as a whole, the complex of contemporary methods of scientific forecasting represents a new and extremely powerful tool for providing sound scientific basis for policies in the region of development of science and technology.*

Table 19 characterizes our ideas on the area of applicability of the considered methods of developing basic functional types of forecasts (МП, ПП, ОП) in generalized form. It should be stipulated that because of still deficient experience in using a number of forecasting methods, the evaluations which are given in the table carry a preliminary character. In the course of further development of the theory and practice of scientific forecasting it is naturally expected that there will be refinement of presentations on the possibilities of different methods of forecasting. The actual functional diagram of classification of forecasting methods also requires refining.

Independently of just how far individual forecasting methods justify our hopes, in our view the major and determining factors in the approach to forecasting methods should be the principle of complex utilization of the available arsenal of forecasting methods. The goal of such an approach is to obtain variants of forecasts which are undergoing development (refinement), being made more specific as experience in realizing initial hypotheses is accumulated.

Under the influence of the ever-growing rates of world scientific and technological progress the optimum forecasting range realizable by one and the same method usually has a tendency to be reduced. In any case, where at the beginning of the century it was possible to predict, for example, patent information 20-30 years ahead, today we

have a depth on the order of 8-10 years - i.e., in this period there is a change for realization and significant innovation.

Table 19.

Class	Type	Group	Forecasting methods	Applicability to		
				nn	nn	nn
I			<i>Extrapolation methods</i>			
	1	—	<i>Extrapolation of data on the magnitude of parameters of objects of forecasting</i>			
	"	"	1 Extrapolation of quantitative parameters of technical equipment.....	x	x	—
	"	"	2 Extrapolation of quantitative characteristics of scientific potential.....	—	—	x
	2	—	<i>Extrapolation of evaluated functional characteristics</i>			
	"	"	1 Extrapolation of data on the fruitfulness of science.....	x	—	x
	"	"	2 Extrapolation of evaluations of quality of functioning of technical equipment.....	x	x	x
	3	—	<i>Extrapolation of system and structural characteristics</i>			
	"	"	1 Extrapolation of the characteristics of the relationships of structural elements in systems.....	x	x	x
	"	"	2 Extrapolation of the indices of the level of complexity of systems.....	x	x	x
II			<i>Expertise methods</i>			
	1	—	<i>Individual expert evaluations</i>			
	"	"	1 Evaluations of the interview type.....	x	x	—
	"	"	2 Analytical evaluations of experts.....	x	x	x
	2	—	<i>Collective expert evaluations</i>			
	"	"	1 The commission method.....	x	x	x
	"	"	2 The referred evaluation method.....	x	—	—
	"	"	3 The Delphi method.....	x	x	x
III			<i>Simulation methods</i>			
	1	—	<i>Logic specimen models</i>			
	"	"	1 Historical analogies.....	x	x	x
	"	"	2 The scenario method.....	x	x	—

Table 19 (continued).

Class	Type	Group	Forecasting methods	Applicability to		
				МН	ПН	ОН
III	2	—	<i>Mathematical models</i>			
"	"	1	Statistical probability models.....	x	x	x
"	"	2	Economic-mathematical models.....	—	x	x
"	"	3	Functional hierarchical models.....	x	x	x
	3	—	<i>Information models</i>	—	x	x
"	"	1	Information models based on patent documentation.	x	x	—
"	"	2	Models of flows of scientific and technical publications.....	x	x	x
"	"	3	Information models of interaction between sciences.....	x	x	x

From this there ensues an imperative need for purposeful improvement of methods of contemporary forecasting. In these conditions the creation of systems of continuous forecasting is especially promising.

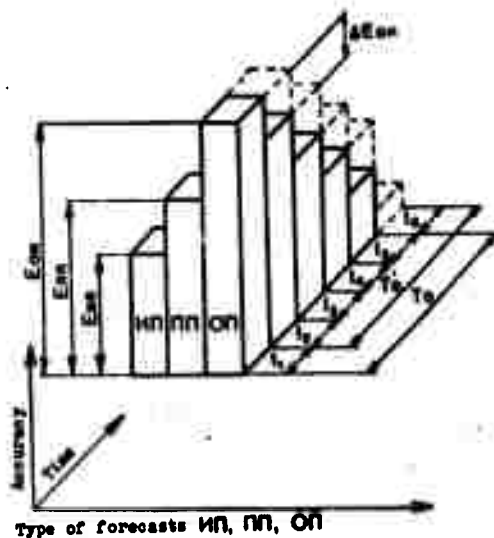


Fig. 45. Diagram of a continuously operating system of scientific and technical forecasting.

Figure 45 illustrates our presentations on this idea. A developed complex forecast (ИП, ПП, ОП) at an optimum range — equal, for example, to 10 or 15 years — is broken down into five characteristic stages, each of which has a respective magnitude of 2 or 3 years. In the period of realization of the first stage the entire complex forecast is elongated by Δt and each of its components is refined by the quantity ΔE . They proceed further in an analogous manner.

We are convinced that the high requirements presented to scientific prediction of the contemporary level of progress of science and technology cannot be met by uncoordinated — however intelligent — statements of outstanding scientists nor by occasional excursions into the realm of the future undertaken on the initiative of groups of researchers, but only by the organization of a constantly functioning system of analysis of trends and forecasting of scientific and technological development*.

Such a system of forecasting, based on the use of modern equipment in computer technology, would be capable of providing operational solution to the fundamental problems stated in this book: constant information tracing of trends in scientific and technological development, systematic technical and economical evaluation of the level of complex technical systems which are operational and which are in the course of research and development, formulation of refined variants of forecast hypotheses and their running reevaluation. All of this should be a powerful factor for increasing the objectivity and the level of optimality of decisions made in the course of controlling the development of the most promising branches of science and technology.

*One of the first subsystems is already operational. This is the automated forecasting system "FAME" (acronym for the English phrase "forecasts and management evaluations." It was created for the NASA management by the firm "General Electric." As a whole several thousand electronic computers are being applied in the USA for the solution of various forecasting problems; these computers are used to fulfill about 40% of the total volume of work inputs in the forecasting field.

The interests of prospective planning of scientific and technological progress in Socialist society and scientifically based realization of a unified state scientific and technical policy in our country imperatively demand that the business of organizing forecasting works, increasing their theoretical and methodological level, and also equipping forecasters with powerful means of data processing be assigned paramount value by the state.

3. Algorithm for organization of forecast developments

Generalizing the material outlined above, we can note the following characteristic features of scientific and technological forecasting which are more or less clearly crystallizing at the present time:

systems approach to the analysis of trends and to forecasting, taking into account the connection of this type of forecast with economic and social forecasts;

complexity of methods of analysis and forecasting using specific ideas of cybernetics, economics, mathematics, and information theory;

the existence of quantitatively determined probability evaluations of the future state of the studied objects;

continuity (systematic nature) of work on analyzing trends and forecasting scientific and technological development;

broad use of contemporary technical equipment for analyzing the vast amount of scientific and technological information, realization of formalized models, and production of computation;

conscious orientation of scientific and technical forecasters toward practical cooperation in prospective planning of the progress of science and technology.

Experience shows that although the bases for determining objects of scientific and technological forecasting may be different (predicted economic requirements; technical characteristics which do not satisfy new requirements; newly discovered capabilities of science; internal

requirements of the scientific and technological process), the urgency of all of them is constantly growing.

In connection with the arrival of work on scientific and technological forecasting at the stage of broadly stated practical developments, there is special interest in generalization of actual experience in organizing and utilizing forecast developments. Our approach to the general algorithm (sequence) of actions during practical forecasting can be outlined in the form of the characteristics of the following basic stages of the work.

1. Request for a forecast. The organization requesting forecast work must do the following: determine the object of forecasting (its span), indicate the desired range of forecast evaluations and outline the proposed forms of the use of the forecast results. An important part of the request for a forecast is formulation by the requester of his understanding of the basic goal of development of the given object of forecasting.

2. Preforecast orientation. It consists in clarification of the working details of the assignment for a forecast, organization of the collection of basic data required for the forecasting operations, preliminary familiarization with existing surveys and forecast evaluations relating to the given object of forecasting, and also the compilation of a detailed plan of the forecasting operations.

3. Analysis of trends and evaluation of the level of scientific and technological development. It is at this stage that actual forecasting activity (МП) begins. A generalized synthesis survey of experience in development of the object is prepared; in it the basic accent is on quantitatively defined evaluations of accumulating trends of development. A mandatory and very important type of work carried out on this stage is evaluation of the level of scientific and technological development of the object as compared both with other countries and with the best Soviet specimens. At this stage there is clarification and formulation of the basic factors and

contradictions which stimulate and inhibit development of the object or which specifically influence its course. Special value attaches to specific evaluation of the economic, industrial, organizational, and actual scientific and technological cause-effect relationships of the given object with other, broader systems.

4. Construction of a "goal - means" matrix. On this stage, which has essential significance for success of subsequent operations, the forecasters give formulations of the following, as objective, logical, and noncontradictory as possible: general goal of development of the given object of forecasting; basic subgoals - specific paths leading to achievement of the general goal; a breakdown of the array of directions possible in principle for carrying out scientific and technological operations which can serve as the means for achieving one or another of the subgoals, and thereby further the achievement of the general goal of development. Special methods of expert evaluations are used to assign to all cells of this matrix the corresponding "weighted" coefficients.

5. Determination and analysis of the possibilities of scientific and technological development. Ranging of the obtained list of key events according to their relative significance (ИП).

6. Formulation of possible sequences of one or another group of key events and tying them into hypothetical networks of program operations. An important problem in this stage of the work is the probability evaluation of the measure of reality and of the proposed periods for accomplishment of the forecast events (ПП).

7. Determination of requirements, evaluation of consequences and prospects of development of the organizational system of the science in connection with the results of the preceding stage of the operations. An important point here is expansion of the evaluation of resources which are required for the achievement of the different paths to one or another goal of scientific and technological development, and also a solution of the problem of the possibility of optimum distribution of resources between different forecast directions.

In this stage the $M\bar{M}$ and $\bar{M}\bar{M}$ forecasts are reinforced and $\bar{O}\bar{M}$ are developed.

8. Formulation of a complex concept of scientific and technological development in the form of a system of argued positions and quantitatively determined indices and parameters. This concept is supplemented by a descriptive document of the "scenario of the future" type, in which the proposed strategic doctrine for development of the branch of science is accompanied by formulation of the most promising (from the point of view of forecast data) of the given directions of development of certain branches of science and technology. The most important and critical portion of the work on this stage is thus the preliminary selection of alternative variants of scientific and technological development.

9. Summary balancing of the system of quantitative indices included in the complex forecast with data on economic potential, resources, etc. So far as we bear in mind that the factors of an economic character will be taken into account on all stages of complex forecasting (particularly broadly on the stages 3, 7, and 8 in the process of $\bar{M}\bar{M}$ and $\bar{O}\bar{M}$, and also during solution of the problem of distribution of resources and selection of variants), the summary balancing has the purpose of achieving more refined matching mainly over the system of expanded indices of scientific, technological, economic, and social development.

10. The preparation and shaping of materials of the forecast for transmission to the requester, assistance in introducing the obtained forecast developments into the practice of making decisions and in the business of prospective and current planning.

In accordance with the accepted concepts of scientific and technological forecasting, the developed *basic forecast documentation* should contain the answers to three mutually connected groups of questions:

give an argued formulation of the variants of possible goals of scientific research and technical development with indication of their comparative significance;

provide a foundation for the predicted paths (sequence of events, stages, types of organization of work) for achieving various goals with indicated probable periods of time required for this;

evaluate the scale of resources (means, personnel, etc.) which are required to arrive at one or another of the goals of the various routes. Provide a foundation for the proposal to distribute resources between different forecast directions.

A scientific and technological forecast must be accompanied by a mandatory *analytical forecast documentation*, whose composition must include the following:

- a brief account of the basic economic, social, political, and other principles taken into account during compilation of the forecast;

- characteristics of the scientific methods used to develop the forecast and refine scientific and technological foundations;

- summary evaluations of the possible time periods, predicted probabilities, and total value of achievement of important key events;

- comparisons (including international) of the scientific and technological level at the time of forecasting and over the perspective being predicted;

- indications of the expected influence of various fields of scientific and technological progress on others;

- formulation and evaluation of possible social consequences;

- fundamental considerations and specific proposals on necessary special levels for realization of the forecast prospects (new types of economic connections and structures, methods of stimulation, acquisition of licenses, etc.).

The documentation which is developed in the course of scientific and technological forecasting and which reflects the contents of the forecast must be regarded as an important scientific result with value to the state. The major requesting organizations should have card files of all scientific and technological forecasts in the area of their interests developed at their request (including those which,

for any reason, were not accepted for realization), and also a file of forecasts which are known from information.

The points listed here could be continued. Their volume and level depend on the specific conditions. However, it should always be kept in mind that analytical documentation of this type facilitates, and frequently to a decisive degree guarantees, the possibility of using forecasts in planning and management decisions. No less important is the fact that it "attaches" scientific and technological forecasts directly to the entire system of economic and social forecasting.

THE FUTURE OF THE SCIENCE OF THE FUTURE

(Conclusion)

In placing before the nation the problem of a manifold increase in the effectiveness of scientific and technological progress, the Communist Party and Soviet Government rely not only on the creative enthusiasm and vigorous energy of our talented people. A no less important role is assigned to the perfection of the business of organization, planning, economic stimulation, and control of scientific and technological progress.

In this historically important business an exceptionally important mission is assigned to the study of science, which brings to bear the apparatus of scientific analysis on the study of the processes of scientific and technological development. It must become a unique theoretical basis for state control of the progress of science and technology.

Attentively studying the lessons of the past, deeply analyzing the contemporary wealth of experience, the study of science strives to understand the science of the future. It is required to use all of its results to serve for more successful paving of the scientific road into the future. In particular, the function of providing concrete presentations on the future of science and technology is inherent to scientific forecasting - the newly developing branch of the study of science with which we are familiarizing you, valued colleague, in this book.

Students of science and forecasters represent only a small section of researchers in the vast army of Soviet scientists. They by no means pretend to the role of leadership of science, but only strive to become businesslike and useful assistants to the people and collectives directly creating the future science and technology. We will always remember the wise observation of V. I. Lenin concerning the fact that "the wisdom of tens of millions of creative people will create nothing immeasurably higher than the very greatest and most brilliant foresight".

In our view the role of the student of science and forecaster in the collective process of predicting the future presents the following basic features. He appears on the stage as the organizer of groups of specialists who possess the knowledge, experience, and intuition required for the development of complex forecasts. The forecaster participates in this work as a researcher, having at his disposal a developed arsenal of special methods of studying the processes of scientific and technological development. At the same time he has the indispensable duty of constantly generalizing actual experience in forecasting, developing theoretical principles of scientific and technological forecasting, and perfecting its special methods and procedures.

The future of our branch of science is closely bound to cooperation with specialists from all branches of science, in comprehension of the specific features of their creative labor, and in the enrichment of the study of science with the most valuable experience in organizing the scientific process as it is accumulated daily in science. The need to assist colleagues to a better understanding of the particular problems and possibilities of scientific and technological forecasting inspired the author to the writing of this book. In many respects this requirement also determined the form of presentation of the material. The author confesses that many problems were left here without an answer, and an even greater number of questions were left unasked. But if the book will assist in the

*V. I. Lenin. Complete Collected Works, Vol. 35, p. 281.

specific and goal-oriented examination of the problems of scientific forecasting, the collective search for methods of their solution, the author will consider its publication to have been justified.

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